TAMPEREEN TEKNILLINEN YLIOPISTO
TAMPERE UNIVERSITY OF TECHNOLOGY

EETU MÄKELÄ

AUTOMATIC ANALYSIS OF BUILDING MANAGEMENT SYSTEMS

Master´s thesis

Examiner: Professor Asko Riitahuhta
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ABSTRACT

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The traditional building management systems are often incapable of detecting impaired performance of heating ventilation and air conditioning (HVAC) equipment, so noticing and fixing the performance errors is up to the skill and motivation of the operator. This thesis examines the implementation of a tool offering automatic analysis to the work of Schneider Electric´s eService unit. The main goal is to examine the effects of automatic analysis to the work description and to the service quality and effectiveness of eService.

The thesis is divided into two parts. In the literature study part, the methods used for automatic analysis of BMS are studied. In order to be able to evaluate the effects of automatic analysis to the service quality of eService: the background of service management is discussed, an introduction to service management is provided and the base for evaluating the development of service of eService is created.

In the second part of this thesis a pilot study was conducted in order to study the usability of automatic analysis in the work of eService and to evaluate the usefulness of one tool utilizing automatic analysis. The pilot study indicated that automatic analysis allows utilizing more data from the buildings, which may dramatically change the work of eService. The effects of automatic analysis on both effectiveness and service quality of eService were discussed.

The results of this study suggest that the diagnostic technologies alone will not result in system efficiency improvements, and that there are some improvements still needed to make the piloted tool more usable. When the capabilities of the tool however are fully utilized there will be improvements in both efficacy and quality factors of eService.

TIIVISTELMÄ

TAMPEREEN TEKNILLINEN YLIOPISTO
Automaatiotekniikan koulutusohjelma
Mäkelä, Eetu: Rakennusautomaatiojärjestelmien automaattinen analysointi
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Perinteiset rakennusautomaatiojärjestelmät eivät kykene itse havaitsemaan huonontunutta suorituskykyään, jolloin suorituskykyongelmien korjaaminen jää rakennuksen käyttäjän vastuulle. Tämä diplomityö tarkastelee automaattista analysointia tarjoavan työkalun implementointia Schneider Electricin ePalvelu -yksikön toimintaan. Työn päätavoitteena on selventää miten automaattisen analysoinnin implementointi vaikuttaa ePalvelun työhön, työn tehokkuuteen ja palvelun laatuun.

Diplomityö on jaettu kahteen osaan, kirjallisuuskatsaukseen ja pilotti- tutkimukseen. Kirjallisuusselvitys käsittelee automaattiseen analysointiin käytettäviä metodeja, ja jotta automaattisen analysoinnin vaikutukset palvelun laatuun saataisiin selville, työssä tarkastellaan myös palveluiden tutkimusta.

Pilottitutkimuksessa tarkastellaan automaattisen analysoinnin käytettävyyttä ePalvelun työssä pilotoimalla automaattista analysointia tarjoavaa työkalua ePalvelun hallinnoimassa rakennuksessa. Pilotin tulokset viittaavat automaattisessa analysoinnissa olevan merkittävää potentiaalia ePalvelun työn kannalta. Automaattisen analysoinnin potentiaalia pohdittiin sekä tehokkuuden että laadun parantamisen kannalta.

Tutkimuksen tulokset kertovat, että automaattista analysointia tarjoavat työkalut eivät yksin pysty parantamaan rakennusautomaatiojärjestelmien tehokkuutta pilotoidun työkalun käytettävyyttä on vielä parannettava täyden potentiaalin saavuttamiseksi. Tulokset kuitenkin vahvistivat oletuksen automaattisen analysoinnin positiivisesta vaikutuksesta sekä ePalvelun tehokkuuteen että palvelun laatuun.

PREFACE

Seven months ago I started this project and now that it is completed I would like to thank the people who made it possible. I wish to thank my advisor at Schneider Electric, Lauri Heikkinen, for his support and for offering precious suggestions and advice throughout the research. I am also grateful for my examiner Prof. Asko Riitahuhta for his constructive comments during the research. I would also like to extend my gratitude to all of the eService experts in the eService unit in Espoo for willingness to assist with my work whenever it was needed. Especially I would like to thank the eService expert Tuomas Posio from providing valuable comments concerning the piloted tool and the work of eService generally.

I am deeply appreciative of my family, who has always supported me through my studies. Last but not least it is the love, support and patience of by beloved wife that has helped me navigate through the writing process and my studies.

TABLE OF CONTENTS

LIST OF ABBREVIATIONS

ABCAT	Automated Building Commissioning Analysis Tool
ANN	Artificial neural networks
BAS	Building automation system
BMS	Building management system
ECM	Energy conservation measure
EE	EnergyEdge
EPC	Energy Performance Contracting
ESCO	External organisation
FDD	Fault detection and diagnostic
HVAC	Heating ventilation and air conditioning
PACRAT	Performance and Continuous Re-Commissioning Analysis Tool
PCA	Principle Component Analysis
SaaS	Software as a service
SVM	Support vector machines
VFD	Variable-frequency drive
WBD	Whole Building Diagnostician

1 INTRODUCTION

This thesis, under the topic; automatic analysis of building management systems (BMS), contains several different aspects on what methods are used in automatic analysis, how automatic analysis is currently used and how it could be better utilized. These aspects are further studied in the body of the work. The introduction focuses on the backgrounds of the thesis, outlines the research questions, purpose and objectives of the research and defines the content of the thesis.

The research questions in which this thesis answers are:

- How can the automatic analysis of BMS be approached?
- What is the potential, applicability and usability of tools offering automatic analysis of BMS in the work of eService?
- How does the introduction of automatic analysis effect on service quality and effectiveness of eService?

1.1 Purpose and objectives of the research

The purpose of this thesis is to answer the research questions thoroughly by evaluating and characterizing the methods used for automatic analysis of building management systems and by presenting some tools using these methods to be able to evaluate how automatic analysis could be used in the work of Schneider Electrics eService. As the work of eService is predominantly concentrated around services, the basic principles or service management are also presented.

The research objectives of this thesis in order to answer the research questions are:

- Identify the methods used for automatic analysis of BMS to highlighting identified best practices.
- Characterize tools with different approaches on automatic analysis of BMS.
- Present the current state of the art of service business, to be able to evaluate the effects of automatic analysis on the service quality of eService.
- Pilot a tool utilizing automatic analytics on a test building, to see the potential, effectiveness and usability of the tool on the work of eService.

1.2 Backgrounds of the thesis

On this day, the large range of equipment that is found from buildings is controlled by building management systems (BMS). The capabilities of the BMS´s have grown steadily over time but the capabilities are not fully utilized. A number of studies have shown that the performance of heating ventilation and air conditioning (HVAC) systems often fail to satisfy the design expectations as a result of poor operation and improper installation of the equipment, sensor failures, insufficient control sequences and equipment degradation. (Wang et al. 2012, Fernandez et al. 2012).

The traditional BMS´s are often incapable of detecting the impaired performance themselves, so noticing and fixing the performance errors is up to the skill and motivation of operator. The operator has to manually go through the system, check the alarms and wait for customer complains. The sole dependence on the BMS operator's skills and the amount of expensive manual labour that the re-tuning of the BMS requires are factors that rise interest on making the process more reliable. There is also an economical aspect in the underperforming HVAC equipment, as a recent study shows that the HVAC systems consume approximately 40% of commercial building energy worldwide. Since commercial buildings account for 35-40% total energy consumption, (Navigant research 2013) optimizing the operation of the HVAC systems is a pronounced way to achieve energy savings. Conservative estimations state that the whole-building energy savings from re-commissioning of the HVAC system would be 13 % in new buildings and 16% in existing buildings (Mills 2009). Some researchers with more optimistic estimates say that the best-case scenario savings wary between 40 and 75 % savings of the HVAC energy in large office buildings which means about 25- 45% savings from the total energy consumption in buildings. They however highlight that "the efficient HVAC configurations and more energy conscious schedules and lockouts may prelude many of the larger savings" (Fernandez et al. 2012).

Schneider Electric has a strong set of offerings to deliver life-cycle services to its customers with a comprehensive approach to energy management. As the work of Schneider Electric's remote services unit eService is concentrated around delivering proactive energy efficiency and webhost services, the potential of automatic analysis on the work of eService is currently of great interest. Incorporating automated fault detection and diagnostics into a broad range of energy management solutions and services is expected to support efforts in new construction commissioning and in maintenance services as well as in improving of the efficacy and service quality of the eService unit.

1.3 Content of the thesis

The thesis begins with the theoretical literature review, followed by the presenting of the results and the conclusions. In more detail: the chapter 2 of the research focuses on the research method, which in this case is a pilot study. In this chapter the piloted tool and the pilot building are presented. The chapter 3 presents the Schneider Electric´s eService unit. The following chapters numbered 4 – 9 focus on the diagnostic methods. The next chapter 10 presents several different approaches on how these methods could be implemented in a tool and the Chapter 11 focuses on the service management theories. The rest of the thesis, Chapters 12-14 are concentrated on reviewing of the results from the pilot and analysing the usability of automatic analytics and of the piloted tool on the work of eService. The last chapter 15 offers conclusions of the work.

2 RESEARCH METHOD

This chapter details out the research methodology for the present study. This research relies on a pilot study approach to investigate the usefulness and effectiveness of the piloted tool in the work of eService. The piloted tool and the pilot building are presented in more detail in the following chapters.

Literature review was also conducted to reveal the potential of automatic analysis and the tools using the methods in the analysis of building management systems. The material for the literature review was collected from a wide range of sources since there was in practise two theory backgrounds; One for the modelling methodologies and the other for the service management theories. The material for modelling methodologies is collected mainly from the sources listed below:

- *Energy and Buildings*
- *ASHRAE Transactions and research reports*
- *International Energy Agency (IEA) projects reports*
- *HVAC&R Research*
- *International Journal of Refrigeration*
- *Journal of Process Control*

The literature review on service management theories was carried out in order to be able to evaluate the effects of the piloted tool to the service processes and to the service quality of eService. The material for the service management theories was collected mainly from the sources listed below:

- *Journal of Service Research*
- *Journal of Services Marketing*
- *Handbook of service science*
- *Journal of Operations Management*
- *Int. Journal of Business Science and Applied Management*
- *Journal of Retailing*
- *International Journal of Service Industry Management*
- *Journal of Marketing*

Multiple other scientific sources, such as case studies, thesis´s, conference papers and interviews were also used in order to get a more thorough understanding of the research areas.

2.1 How the pilot was carried out

Utilizing building data to its full potential may dramatically change work of eService and actually the whole building industry. There are still barriers slowing the progress. So in order to study the usability of automatic analysis and to evaluate the usefulness of one tool utilizing automatic analysis, a pilot was conducted in a test building.

The pilot started with a start-up meeting on the beginning of 7/2013 where the pilot was discussed and the next steps for the pilot were determined. The first phase of the pilot, consisting of collecting data from the site, was started soon after the first meeting. The data included information concerning the building automation system, points list and general system information. In the beginning of 8/2013 the first phase of the pilot was completed. The next phase consisted of two parts. The first part was the setup and configuration of the piloted tool to work with the 16 air handlers in the piloted building. The first part of the second phase was completed in the midway of 8/2013 when the piloted tool offered its first reports. The second part of the second phase was the setup and configuration of the piloted tool to work with the two cooling and heating systems in the piloted building. The second part of the second phase was completed in the 9/2013 when first reports from the cooling and heating systems were generated by the piloted tool.

The results from the pilot are analysed in the results and discussion chapters.

2.2 Introduction of the piloted tool

The tool which was used in the pilot uses modern hardware and open communication protocols to access data from a variety of sources from different kind of buildings. The tool monitors real time data and historical trend data from building management systems and utility metering system on equipment level and has therefore a bottom-up approach. The data collected by the tool is automatically analysed every day to identify malfunctioning equipment, to diagnose problems and to identify savings opportunities by suggesting repairs to problems or adjustments to control settings. The tool under research has a cloud based data storage, where the data from a building is turned into easily understandable information that user can use to make decisions about operating and managing the building. The information is presented in an online interface with detailed findings which include specific and prioritized cost and energy savings opportunities. The tool works as an another element next to other energy management solutions and services, giving the confidence to make fact-based decisions for improving energy use, operational efficiency, comfort, and financial performance throughout the building's life cycle.

The tool has built-in libraries, which are used for producing energy efficiency and maintenance actions for the users. With the mapping of specific building sequences and engineering parameters, the diagnostic algorithms of the tool are tailored to individual building and its system configuration.

The tool is built on a large data collection and storage cloud system. The cloud based platform is broken up into components for scalability and efficiency in managing data and applications. The cloud works as a data centre made up of a network of servers which can be used as necessary for a given website or application.

The tool creates easily understandable reports, making them more useful for vide audiences. For example, if simultaneous heating and cooling on an air handler is found the tool would state: "The preheating coil and cooling coil are heating and cooling simultaneously", and then providing a list of possible causes such as "Valve is in manual override" or "Valve is leaking by", and estimate the cost of wasted energy such as $5,000 over the month. With such a report in hand, the operator can go check valves and sensors of the faulty air handler, confirm the issue, and make repairs or call in a service contractor.

2.3 HVAC/BMS systems in the pilot building

The HVAC system along with the building automation system in the pilot building is controlled by the SmartStruxure building management system. SmartStruxure is powered by StruxureWare™ building operation software, which provides integrated monitoring, control, and management of HVAC, energy, lighting, and other critical building systems.

There is also a vast amount of controlling equipment in the building, but since the pilot consisted from only the air handlers and the heating and cooling system, they will not be covered. The figure 1 presents an overall view of the equipment in test building and reveals the scope and schedule of the pilot.

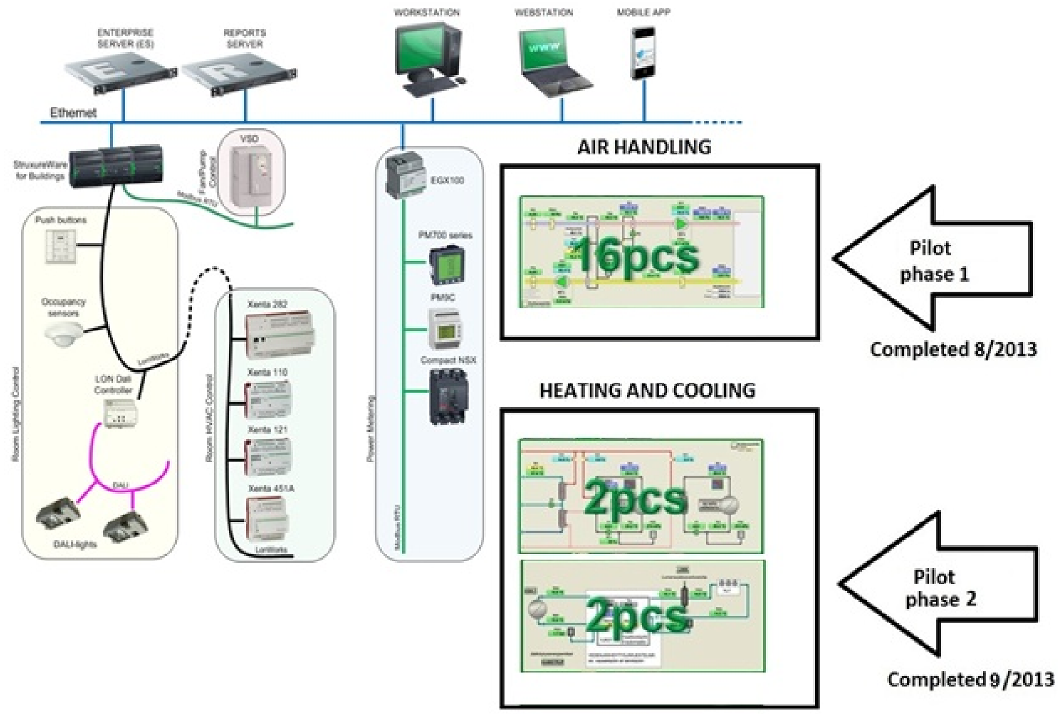


Figure 1. Overall view of the equipment in the test building revealing the scope and schedule of the pilot.

The heating in the building is carried out by two radiator systems heated by district heating. District heating is centrally produced heat which is distributed to through pipes buried in the ground. District heating enables the use of fuels and waste heat that would otherwise be difficult to use effectively in the energy system. The district heating is also generally considered as a reliable and robust heating source. The heat from the district heating is used for space heating and domestic hot water preparation. The hot water is separated from the water in the district heating network.

The cooling system in the building consists of two water coolers which are used to cool the coils in the air handlers and to cool the domestic cold water when the free cooling mode cannot be used. The cooling system enters the free cooling mode when the outside temperature remains between -5 °c and 5 °c for at least three hours.

There are 16 air handlers in the building that are used for building ventilation and for distributing the cold produced by the cooling system. The major components of the air handlers are the supply air and return air fans and the preheating, cooling and heating coils. The air handlers are push-through fans meaning that the fan is located before the coils. There are also heating and cooling control valves; recirculated air dampers as well as exhaust air and outdoor air dampers and finally the ducts which transfer the air to the conditioned spaces.

Inside the air handlers, the air is pushed through the coils where the desired amount of heat is added or removed from the air. The air is drawn by the supply fan and its speed is controlled with a variable-frequency drive (VFD). The air handlers in the building are used during the whole year for circulating air and for cooling during the summer time. Although the heating could be done with the air handlers, the district heating connected to the radiator system is more energy efficient and is therefore used exclusively for heating. The air handler is turned on according to the air conditioning schedule and until the motion sensors notice movement, the air handler air flow is kept at its minimum. When the motion sensors in the air handler's area notice movement, the air flow begins to rise. The speed and level of the rise depends on the control sequences, which follow different variables, like the carbon dioxide content, the temperatures and the movement in the controllable areas. The supply air is distributed to the zones through the supply air duct. Ducted return air is drawn through the return air fan also controlled with a VFD. The speed of the supply fan is modulated to maintain duct static pressure at the setpoint. The exhaust air, recirculated air, and outdoor air dampers are used to regulate the air flow in the air handler.

3 ESERVICE INTRODUCTION

One of the main purposes of this thesis is the evaluation of how automatic analysis could be used in the work of Schneider Electrics´ eService. The work of eService is therefore further explained in this chapter.

Typical industrial sector services include field services, retrofit services and advanced services. (Karandikar and Vollmar 2006). Field services are a traditional view of service in the industrial sector consisting of fixing equipment breakdowns as well as carrying out regular preventive maintenance. Field services are usually performed on the customer´s site. Retrofit services are project oriented services concerned with restoring equipment to the original performance level. Advanced services typically require the most in-depth knowledge of the customer’s site. Advanced services often include performance optimization, software migration, recommendations for improving the customer's plant and offering of detailed analyses and preparing reports. (Karandikar and Vollmar 2006). The development of information technology has enabled the development of remote services, which are new types of services in the industrial service sector. According to Simmons et al (2001) services which have demanded direct customer contact cannot however be totally replaced with remote services. This however rarely even is the target of offering remote services.

Customers increasingly demand solutions that utilize building data to achieve savings in energy consumption and to improve the efficacy of the maintenance staff and the operators. The solution providers must therefore adapt to the changing needs of the market by developing new services, like the eService by Schneider Electric. eService is Schneider Electric’s remote services unit delivering proactive energy efficiency and webhost services consisting also of predictive maintenance actions, equipment performance monitoring and optimization. If following the categorization of Karandikar et al (2006), the service offering provided by eService is an advanced service offering, with elements from both retrofit services and field services. eService does not directly offer field services, but instead the eService unit works closely with the maintenance unit. Maintenance unit provides the more traditional field services and implements the energy saving solutions designed by the eService unit.

eService unit currently consists of 50 personnel, which are spread around Finland in several cities. eService therefore follows decentralized model to be able to provide knowledge of local circumstances and to be able to show local presence. eService has remote service centrals in six locations around Finland.

The eService personnel have two different work descriptions depending on the focus of the work. The first work description is of the eService personnel who are responsible mostly for the basic functions of eService. The basic functions of eService consist of energy efficient use of the BMS, which is carried out by checking and adjusting the preset values and control loops in the BMS´s. To ensure that the BMS is functioning energy efficiently, the operating schedules and control settings of the HVAC system are also adjusted from the building management system. The basic functions consist also from monitoring the functionality of the building automation by regular inspections using remote connection, further ensuring that the BMS is working energy efficiently and the indoor conditions are in order. The basic eService tasks also include handling of alarms from the building automation system although the degree of responsibility of checking the alarms can differ depending on the eService contract. Building auditions are also a part of the basic eService. Buildings are always audited when the service starts and auditions can be carried out also in other situations.

The second work description of the eService personnel is focused more on the EnergyEdge (EE) programs designed for commercial buildings. The objectives of an EnergyEdge program are to: help customers to audit, realize and sustain energy savings. This comprehensive program can save up to 20 % -30 % of utility costs and improve the life cycle cost of a building (Schneider-Electric.com). The EE projects include an energy audit and facility analysis to discover energy saving opportunities. The EE eService personnel accompanied by energy engineers study the building's operations and energy use and then make decisions concerning what energy conservation measures (ECMs) will be implemented. The EnergyEdge program focuses on high energy use problems backed by monitoring and support services. The figure 2 below presents the generalized process of EnergyEdge projects.

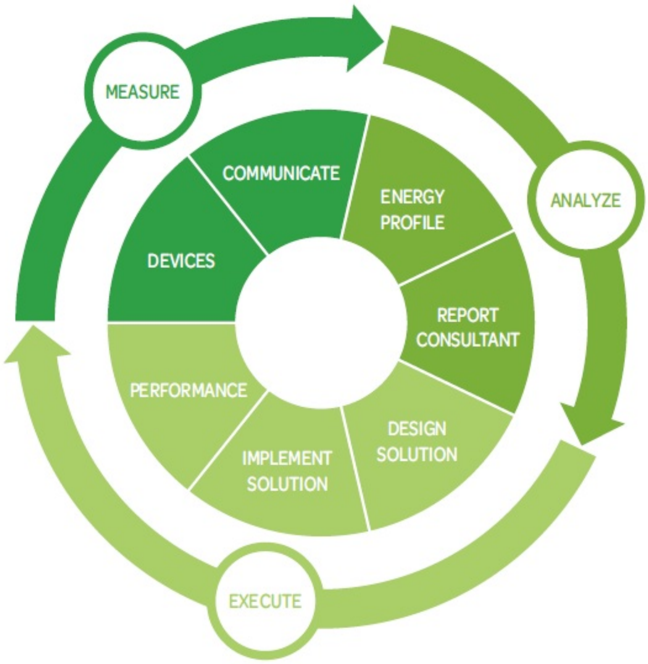


Figure 2. The generalized process of EnergyEdge projects (Schneider-Electric.com).

The EE savings programs are a one form of Energy Performance Contracting (EPC) projects. According to European commission Institute for Energy and Transport: “Under an EPC arrangement an external organisation (ESCO) implements a project to deliver energy efficiency, or a renewable energy project, and uses the stream of income from the cost savings, or the renewable energy produced, to repay the costs of the project, including the costs of the investment. Essentially the ESCO will not receive its payment unless the project delivers energy savings.” Figure 3 illustrates the concept of EPC projects.

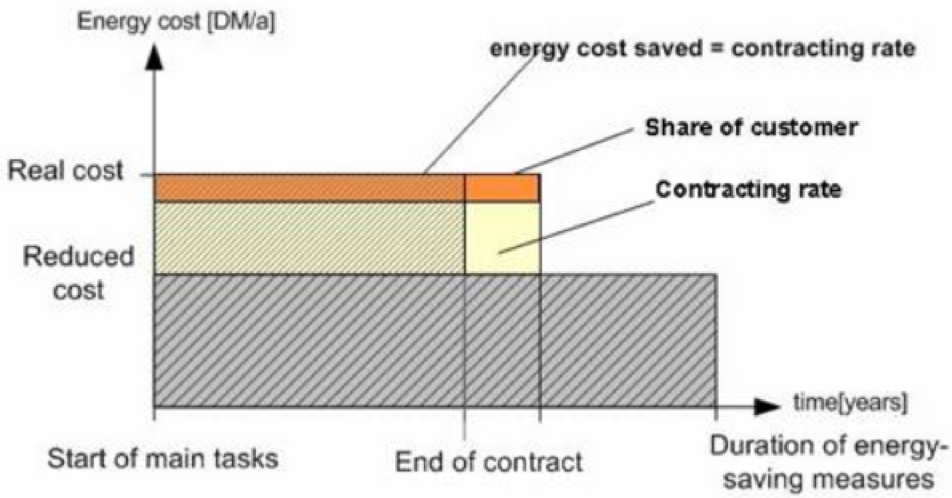


Figure 3. The concept of EPC projects (European commission Institute for Energy and Transport).

The approach of the EE projects is therefore based on the transfer of technical risks from the client to the solution provider. In the EE program, the income is based on demonstrated performance. The EE programs offers means to deliver infrastructure improvements to facilities that lack energy engineering skills, manpower or management time, capital funding, understanding of risk, or technology information (European commission Institute for Energy and Transport). There are two main contracting models in the EPC projects: the shared savings model and the guaranteed savings model.

"Under a shared savings contract the cost savings are split for a pre-determined length of time in accordance with a pre-arranged percentage. There is no 'standard' split as this depends on the cost of the project, the length of the contract and the risks taken by the ESCO and the consumer." (European commission Institute for Energy and Transport)

"Under a guaranteed savings contract the ESCO guarantees a certain level of energy savings and in this way shields the client from any performance risk." (European commission Institute for Energy and Transport)

The savings are accumulated by implementing fixes and improvements to the HVAC system in the building and by setting the BMS system to work energy efficiently. The work EE eService personnel therefore is heavily concentrated to the beginning of the project, where the goal is to achieve savings in rapid timeframe.

Finally, reporting is also a part of the work of the both types of eService personnel. The reporting tasks usually include monthly energy monitoring reports, which can include reports concerning the indoor conditions and the alarms also. The EE eService personnel also generate reports concerning the savings projects an agreed period of time, which is usually in every quarter year. The energy savings reports usually include the achieved energy savings and fulfilled actions in buildings. A yearly report generated savings report also includes cumulative savings.

Towards the diagnostic methods

One of the main purposes of this thesis is to evaluate and characterize the methods used for automatic analysis of building management systems. To identify the methods used for automatic analysis of BMS, highlighting the identified best practices, the diagnostic methods are presented in the following next chapters.

4 DIAGNOSTIC METHODS

The diagnostic methods described in this section are the most potential methods applicable to the automatic analysis of BMS. The most important capability of any automated diagnostic method is the ability to distinguish correct or, at least, normal operation from incorrect or abnormal operation. (Peci and Battelle 2003). The main idea of this chapter is to describe how each technique would execute the distinguishing between correct and faulty performance and identify any constraints that would limit the application of the technique. The strengths and weaknesses of each technique are also discussed.

There are several different methods to diagnose the state and condition of the HVAC system. The major difference between the different methods is the knowledge used for formulating the diagnostics. Diagnostic methods are divided in varying ways in the literature, mostly because the different methods overlap in several cases. The most simple and clear categorization is the division to knowledge based methods and process history based methods, which fall into several sub categories as shown in the figure 4. The division is based on the approach the methods are using for formulating the diagnostics. These methods are presented and analysed in the following chapters.

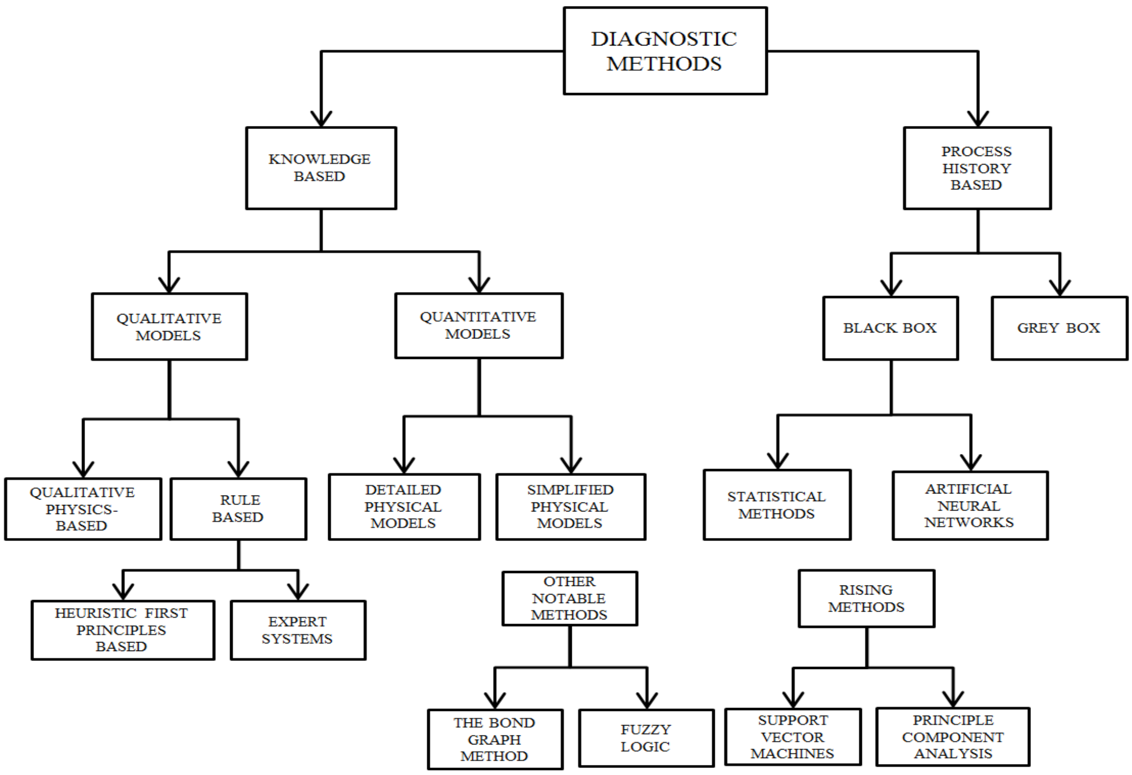


Figure 4. The categorization of Analytic methods, formulated using the work done by (Katipamula and Brambley 2005a, Venkatasubramanian 2003a, 2003b).

5 KNOWLEDGE BASED QUALITATIVE METHODS

Knowledge based diagnostic methods require information regarding the modelled system. This information is often called a priori knowledge. Knowledge based systems can be divided into qualitative and quantitative methods. (Katipamula and Brambley 2005a). The boundary between the methods can become unclear in some approaches, but this division into two main categories provides a useful scheme for categorizing the methods presented in this paper.

Qualitative models can be defined as “Functional relationships between the inputs and outputs of the system that are expressed in terms of qualitative functions centred on different units in a process. “ (Venkatasubmarian 2003b). Qualitative modelling techniques are often based on a priori knowledge of the system. Qualitative models are usually formulated based on qualitative physics, causal reasoning or expert systems. For example, a usual form of qualitative modelling is a set of rules produced by expert systems. (Katipamula and Brambley 2005a). Qualitative models can be used in versatile situations, but two main reasons for choosing to use a qualitative modelling technique can be recognized (Gruber 2001):

1. Qualitative modelling technique is preferred if the modelled process is unsuitable for being analytically expressed, so that the descriptions can only be made using general qualitative rules expressing the different known measured control and disturbance inputs, states, parameters of outputs of the process.

2. If the modelled process is described by a really complex analytical model or if the parameters of the models are hard to quantify, there is reason to prefer qualitative modelling technique, because qualitative models are less complex and also less parameters are needed for the formulation process of the model.

In both cases, the intention is to avoid relationships that are hard to form and to avoid dependencies on parameters that are hard to set or identify. There are also shortcomings with the qualitative models, which result from the simplifications and the replacement of the hard-to-come-by parameters. (Gruber 2001). For example fewer types of faults can be detected with qualitative models when compared to quantitative models and the fault level of the faults that can be detected is coarsened. A transformation of measured data into qualitative values is often required when using qualitative methods and this phase is often called the transformation phase. These parameter transformations, for example when turning quantitative values into qualitative parameters, bring inaccuracies

(Gruber 2001). Besides the transformation phase, qualitative methods often include also a knowledge base phase and an evaluation phase. In the knowledge base phase the correct behaviour of the system is recorded and in the evaluation phase the violations of the rules are checked and the current operation is compared to the correct operation.

Qualitative models can be further divided into qualitative physics- based and rule based models. Both these of these models use causal knowledge regarding the process of the system to formulate diagnostics, but the formulation of the rules identifying the faults is so different that the division to these two subcategories is needed . (Katipamula and Brambley 2005a).

5.1 Rule based methods

Rule-based modelling techniques use a combination of if-then-else rules and an inference mechanism that searches through the rule-space to draw conclusions concerning the state of the system. The difficulty of the rule based modelling is to find a complete set of rules covering most or all of the different events happening in the system. Simple systems, which can be described with a small amount of rules, can be implemented in a simple program language like C, but more complex systems are better covered with more sophisticated tools like expert systems. Since the data controlled by building management systems is rarely simple, rule based systems used in the analytics of the BMS are most commonly based on expert knowledge or on first principles. (Katipamula and Brambley 2005a).

5.1.1 Expert systems

An expert system is a system that tries to mimic the cognitive decision making process of a human with expertise in the field who is solving a particular problem. Expert systems consist of a knowledge base and an inference engine. Expert system usually does not have an understanding about the physics governing in the system and when a system is complex, the tree of the rules grows rapidly. Therefore expert systems must be thoroughly validated to check that their knowledge base is complete and consistent. Even though the database would be validated, there is the problem which is always with this kind of shallow knowledge; a poor performance in cases where a new condition, which is not defined in the knowledge base, is encountered. (Venkatasubramanian et al. 2003b). Some expert systems allow users to evaluate if the conclusions are correct or not, essentially adding a confidence levels for the computed information.

In the 1980s expert systems flourished and they were largely deemed as a competitive tool to sustain technological advantages by the industry. By the end of 1980s, over half of the Fortune 500 companies were involved in either developing or maintaining of expert systems and universities offered expert system courses. (Enslow 1989). Expert systems did not however live up to their hype because it became soon clear that creating deep enough knowledge bases was costly and time-consuming. Also one reason why the expert systems have not grown in popularity like it was expected in the 1980s is the inefficient methods of acquiring knowledge. The process of knowledge acquisition consists of actually acquiring the knowledge, which is usually done with interviews, sorting the knowledge and expressing it in the form of a knowledge base. According to the Annex 25 (1995) research the "process of knowledge acquisition ... is more difficult than generally considered, requiring a tremendous amount of time, money, and effort." The knowledge bases cannot be easily updated neither. If big chances are introduced to the system often only the knowledge engineer who knows the system can make revisions easily. (Annex 25 1995). To make the usage of expert systems more usable in the areas of automatic analysis of BMS, there is a clear need to develop ways for operators to make and maintain knowledge bases by themselves. Although expert systems did not live up to their hype, they are still used in a wide range of arenas from health care to automobile design. (Durkin 1993).

Depending on the depth of knowledge, there can be recognised three different approaches to expert-system development: the low road, the middle road, and the high road. (Brown 1984). The low road involves flexible programming environment enhanced by clear user interface. The primary concern with the low road approach is achieving high efficiency by keeping the required knowledge base small. Also parallel programming techniques which prevent the need to change the knowledge base frequently are used for achieving the high efficiency. The low road approach is well suited in situations where efficiency is needed for example in applications where there is a large search space of possible solutions. (Bobrow et al. 1986). The high road approach involves building a system that deepest representation of knowledge, relatively complete coverage of some subject matter, and that the knowledge can be used for more than one purpose. Systems with high road approach often require long chains of reasoning from first principles to practical results. Expert systems with high road can carry out diagnostic reasoning and qualitative simulation, and can reason from first principles about how physical devices work. However high-road systems are usually too slow for real-world applications, since they take only very small steps toward the solution of big problems and therefore they are mostly used for research. (Bobrow et al. 1986). Middle-road systems fit between the two extremes. They involve explicit representation of knowledge and some direct programming may be used resembling the low road approach. (Bobrow et al. 1986). Compact problem solving tactics are often rather used with middle road approach than first principles. A key characteristic of middle-road systems is that they are sharply focused on a single task and incorporate knowledge specialized for the task, but the explicit representations often do not specify the limitations of that knowledge. Middle and low road expert systems are called shallow systems because most of their reasoning chains are short. For most applications, the middle road is often referred as the most effective approach for building expert systems. (Brown 1984).

The researchers from IEA in project Annex 34 (2001) have recognized that a key point for developing expert systems for automatic analysis of HVAC systems is the avoidance of case specific rules and instead a systematic method for generation and simplification of rules should be adopted with the system. This is especially important when diagnosing complex HVAC systems with several operating modes. (Annex 34 2001). When the patterns from all classes of operation in the system are easy to identify, the expert systems are a good choice for deployment. (Haitao 2012). Expert systems are normally deployed using expert system shells, which hold all the components needed for deployment. Shells usually consist of the five following building blocks (Gruber 2001, Peci and Battelle 2003)

1. *The knowledge base block* contains the expert knowledge captured in rules and is the most important among the building blocks. The knowledge base is essentially a large base of if-then-else rules, which are usually gathered through interviews with the experts in the particular area. The rules are stored by a simple rule collection expressing the rules, or by a decision tree. The rules represent relations between objects, their attributes and values (Gruber 2001).

2. *Inference and flow control block* contains an interference engine, which searches the knowledge base and the configuration database trying to draw conclusions using an inference mechanism and a flow control strategy. The flow control strategy decides how the rules are processed. It decides where to begin and how to handle conflicts. The most common interference mechanism is a logic rule called *modus ponens*, which uses deductive reasoning process and states that "if the premises of a rule are true then its conclusions are also true" (Gruber 2001) To decide whether the premises are true or false, thresholds are used as rule parameters of the evaluation process.

3. *Input data block* is used for loading the measured data from the process into an archive database. The measured data contains sampled time series of sensor signals and controller outputs, which have to be pre-processed by comparing data with upper and lower bounds, in order to detect invalid or missing data.

4. *Output data block* receives and handles the outputs from the inference and flow control block and displays them in different forms, depending on the needs of the user.

5. *Configuration block* offers a user interface, which is used for loading configuration information about the process. The configuration information in the case of BMS supervision would consist of building topology, the HVAC system details, point definitions/ locations and functions with operational and control parameters.

Expert systems have not shown a huge potential in the field of HVAC diagnostics, although expert systems can be used effectively for solving well understood but poorly structured fault detection problems for example in cases where symptoms, failure mechanisms and heuristics are available or could be developed easily. This has been seen from the few positive experiences from process and manufacturing industry, where monitoring systems have been deployed with expert systems for demonstration purposes. Still widespread usage has not been seen, mostly because of the reliability issues with the expert systems. (Peci and Battelle 2003, Haitao, 2013). Most existing expert systems are designed to mimic the work processes of a building operator. Expert systems can only be as intelligent and insightful as the creators, thus hard work and professionalism is required from both the knowledge engineer interviewing the experts as well as the expert being interviewed. The creators must clarify the users about the boundaries in which the knowledge applies and appropriately qualify the statements received from the expert system. According to the research by Peci and Battelle (2003) it is unlikely that expert systems would achieve high levels of reliability that would be required for the uses of automatic analysis of HVAC equipment and BMS systems, and if some systems would, the high variance of the HVAC equipment and the difficult validation process would prevent the spreading of the knowledgebase without alterations.

5.1.2 Heuristic first principles based rules

The heuristic rules are practically derived rules or tested and proven approximations that are known to provide correct results. For example rules of thumb are heuristic rules. Heuristic rules are often derived from first principles or developed empirically by observing the performance of the system. The first principles based approach usually reflects physical laws such as mass balance or heat transfer relations, but the approach can be qualitative also, like in the case of automatic analysis of BMS, where first principles based heuristic rules reflect the device implementation knowledge. The device implementation knowledge is often cumulated through experience and it consists primarily of the conceptual understanding of the system. (Peci and Battelle 2003). The device implementation knowledge is used to specify a model that is forming a basis for detecting and evaluating differences between the actual and the expected operating states. The actual operating states are determined from the measurements and the expected operating states and values of characteristics are obtained from the model. (Katipamula and Brambley 2005a).

Heuristic first principles based rules are easy to understand and implement on software and they are acceptable to testing and additional refinement. The method provides a convenient way to put up an analytics engine for isolated system and it provides short-cuts when comparing to more time and money consuming systems. On the other hand, heuristic first principles based rules do not work well outside of the area they were developed for and they cannot even be used in all the places that more physics- based methods can be. In addition applying heuristic first principles based rules for whole building would most likely offer too simplistic analytics and unreliable performance. (Peci and Battelle 2003).

5.2 Qualitative physics based methods

Qualitative physics deals with states, behaviours and transitions. The transitions between different states happen in sequences and the behaviour is a sequence of transitions and states. For example in air-conditioning systems, the states might consist of temperatures, pressures and air flows. “The rules governing transitions would be the differential equations describing the evolution of the states, and "behaviours" would correspond to legitimate solutions of the system differential equations.” (Annex 25 1995). Qualitative physics based analytic methods are used mostly in two different ways:

1. The first way is “the derivation of qualitative confluence equations from the ordinary differential equations governing behaviour of the process.” (Katipamula and Brambley 2005a) these equations can then be used to derive the qualitative behaviour of the system by using qualitative algebra.

2. The second approach involves using qualitative behaviours that are derived from differential equations governing the physics of the system, as a source of knowledge in the analysis. These methods begin from a description of the physics governing in the system, and then construct a model to determine the behaviour of the system. (Venkatasubramanian et al 2003b).

The biggest advantage of qualitative physics-based models is that they enable conclusions about a process without exact expressions about what is happening in the process and without precise numerical inputs. In some cases, qualitative models are able to offer partial conclusions even with incomplete and uncertain knowledge concerning the system and inputs. (Katipamula and Brambley 2005a).

6 KNOWLEDGE BASED QUANTITATIVE MODELS

Quantitative model based methods count on analytical redundancy and use explicit mathematical expressions representing the process and operating states in order to diagnose and isolate findings. Analytical redundancy refers to sensor measurements and other measured variables, which are compared to calculated values, in contrast to the more often familiar physical redundancy, where measurements from several sensors are compared to each other. (Katipamula and Brambley 2005a). The residuals are the inconsistencies between the expected and the actual behaviour of the process. According to Venkatasubramanian et al (2003a) the biggest advantage of using quantitative models is the slight control over the behaviours of these residuals. However quantitative models are often an impractical choice for modelling as the high complexity and dimensionality the nonlinearity of the process and the lack of good system data often limit the usefulness. (Venkatasubmarian 2003a). Quantitative models can be steady- state, linear dynamic or nonlinear dynamic and they can be divided in two groups: those based on detailed physical models and the ones based on simplified physical models.

6.1 Detailed physical models

Physical models are obtained based on knowledge about the physical principles in the system under supervision. In the physical model based analytics of the HVAC equipment, the behaviour of the system and the values of outputs are predicted or estimated and then compared to the measured performance or output. The outputs can be for example temperatures, pressures and flow rates or in case of model parameters they could include heat transfer coefficients, numbers of fins or types of refrigerants. (Katipamula and Brambley 2005a). Besides being based on the behaviours of the equipment, the physical models can be developed based on the first principles of physics also, where the model consists of mathematical parameters and equations based on mass, momentum, energy balance and heat transfer theory. (Haorong Li 2011).

Detailed physical models are formed by using detailed physical equations based on detailed knowledge of the physical relationships and characteristics of all components in a system. With detailed physical models, a deep knowledge of the system is necessary. Detailed physical models are in the case of mechanical systems based on a set of detailed mathematical equations based on mass, momentum, and energy balances along with heat and mass transfer relations. Detailed physical models can simulate both normal and faulty operational states of the system which is often more than is needed.

(Haorong Li 2011). Detailed physical models can also simulate the transient operations of a system more precisely than any other method. Especially dynamic physical models excel in capturing of faults at the time of transient operation. A detailed physical model can also help to supplement the training data needed for data driven approaches, as they are capable of extrapolating performance expectations. (Katipamula and Brambley 2005a). According to the research by Haorong Li (2011), detailed physical model with robust and accurate characteristics is in theory the most suitable tool for automatic analysis and diagnostics purposes, because of the above strengths.

Despite the several strengths, it is still difficult and expensive to develop a detailed robust and accurate physical model for the whole system. The main reason is that the detailed physical characteristics must be specified to a level where the application of the method in near real-time is computationally intensive. For example, "*to truly model the transient phenomena in a heat exchanger of a vapour compression system, it is necessary to create a detailed inventory of the mass distribution at all points in the heat exchanger as a function of time, requiring solution of the Navier-Stokes equations for compressible flow.* "(Bendapudi and Broun 2002) It is difficult to even apply detailed physical models to separate complicated components like heat exchangers where several nonlinear equations, that are difficult to solve, are needed for modelling, not to mention modelling all of the equipment in the building. (Haorong Li 2011). The difficulty emerges especially in real buildings with poorly managed operation conditions, when trying to relate theoretical performance expectations to the finished system. Systems and equipment in real buildings rarely achieve the capacity achieved in the laboratory tests as systems are subject to environmental loading and installation conditions which differ from those assumed for design and used for laboratory testing. (Peci and Battelle 2003). Another major problem with the detailed physical models comes with the robustness requirement as there are several uncertainties in the physical parameters of an operating plant. The problem is particularly highlighted when robustness is hard to achieve, for example when working with more complex system models, as the heavier the analytics technique depends on the model the more important the robustness becomes . (Venkatasubmarian 2003a). The challenges in re-using of the developed model are the final stumbling block for the detailed physical models. The models are often validated for a single piece of equipment only, which complicates the usage for even with the same kind of equipment which is manufactured by different company. The re-usability problem was highlighted in the research by Bendapudi and Braun (2002), when they formed a dynamic model for centrifugal coolers using a detailed physical model. The researchers come to a conclusion that the model could not be readily used with similar coolers, since the model would require addition of appropriate controller, compressor details, valve behaviour and other specific details from the cooler manufacturer in order for it to work correctly.

Because of the presented challenges, it seems unlikely that the detailed physical models would be used extensively in the future, which is backed up by many researchers: (Katipamula and Brambley 2005a, Haorong Li 2011, Peci and Battelle 2003). It is just too time consuming and expensive to use these heavy detailed physical models.

6.2 Simplified physical models

Simplified physical models in contrast to detailed physical models use empirically derived assumptions and approximations with the physical equations. Simplified physical models can be derived based on the mass and energy balance of the system granting accuracy to the model, but they also employ a lumped parameter approach, which is computationally simpler. In a lumped parameter approach the space-time partial differential equations in mass and energy balances are transformed into ordinary differential and algebraic equations, which can be solved with engineering based calculation methods (Katipamula et al. 2005a, Liang 2007) Often used simplifications are assumptions about the heat transfer. The conductivity of walls is often assumed constant and the heat conductions through wall can be assumed to be one dimensional and steady state. Simplifications can also be based on data analysis. For example the data analysis by Siuy et al (2012) revealed that the heat transfer between two adjacent rooms controlled by a same VAV with the same thermostat setpoint can be neglected. This was based on the observation that the temperature difference between the outside air and the air in a room was 2200 % higher than the temperature difference between two adjacent rooms. Thus the heat convection between the outside and room air dominates the heat convection between the adjacent rooms. (Siuy 2012).

There are several overlapping strengths and weaknesses with the simplified and the detailed physical models. (Katipamula and Brambley 2005a). Basically the strengths with simplified models are the same with the detailed physical models, but there are some accuracy deteriorations due to the simplified assumptions. Similarly the weaknesses of the detailed physical models resemble the simplified physical models, with the difference that simplified models are less computationally demanding and demand less time and effort in the developing phase.

7 PROCESS HISTORY BASED METHODS

With the process history based methods, or more commonly data based methods, the known inputs and outputs are mathematically related to the measured inputs and outputs. (Katipamula and Brambley 2005a). With data based methods this process of relating outputs to inputs is called training. The input/output data achieved by training is therefore the source of knowledge in the data based methods. The data based methods can also consist of elements of first principles or rule based systems, but the approach is still predominantly empirical. (Peci and Battelle 2003). The idea of training is to train the model until the output of the model is close enough to the target output from the training data. Training data consist from data sets where both system inputs and the corresponding system outputs are known. When properly trained, data based models faced with patterns similar to those used for training can recognise the patterns and generate meaningful results (Haorong Li 2011, Annex 34 2001). After training, the models are tested against other data sets known as test data sets, which contain input data and corresponding output data to validate the models. Obtaining good training data that would cover the different input/output pairs from all four weather seasons is problematic itself, but adding that many necessary measurements are not readily available or are of bad quality and sending test signals to the system is often limited, there are several challenges in implementing of data based models . (Annex 34 2001). Obtaining faulty data is essential for the model to learn to recognise the performance problems and faults happening in the system. The problem is that the faulty data is especially difficult to obtain, since introducing faults to the system just to get the training data is often not possible, since the faults would most likely cause the deteriorating of the indoor circumstances, which reduces tenant comfort and can cause added energy consumption . (Annex 34 2001). There are problems with re- using a good training data also, since most commercial buildings are too different in terms of design, operational patterns and environmental conditions that a training data from one building might not be at all suitable for another building. (Peci and Battelle 2003).

Most of the weaknesses with data driven methods are connected to collecting good enough data for the model to work effectively in the most circumstances. If there for some reason are good data readily available, the data based models are quite simple to develop. The data based methods are well suited in the pattern recognition, for which they are actually developed for and what detecting chances in the system most often is. For example a mission to detect a faulty operation from an economizer working in a building could be done easily with the pattern recognition features of the data based methods. The pattern recognizing diagnostics tool would have the mapping of the temperature variations caused by a faulty economizer recorded and when the corresponding pattern would emerge, the tool would easily recognize it. (Peci and Battelle 2003).

The data based methods can be related to physics, be based on prior knowledge or they may not have any physical significance. The subdivision of the data based methods is done according to this feature. The models that have some physical information added or require some prior knowledge concerning the system, are called the grey box models and the models with no knowledge about the underlying physics are called the black box models. (Katipamula and Brambley 2005a).

7.1 Black box

The black box models are developed without any understanding about the physics governing in the system. The knowledge in the black box models is formed purely from the measurement data acquired from the dynamical tests done in the system. (Haorong Li 2011). Since the black boxes are developed purely from the measurements, it can be hard to understand the reasoning behind the decisions made by a black box model, since it is difficult to try to obtain any physical insight from the process. (Annex 34 2001). The black box models require less time to develop than any of the knowledge based systems, assuming there are good data readily available. (Katipamula and Brambley 2005a). However the prediction accuracy is just as good as the quality of the training data which was used to develop the black box model, since the model cannot extrapolate outside the data range for which it was developed for. If the training data is sparse and missing important parts, the black box developed using this data is likely to perform unreliably in the cases where the missing data ranges are met. If there are no data available, the development of the black box models is impossible. (Peci and Battelle 2003). In the figure 5 below, the basic principle and data reliability of the black box following historical data is presented.

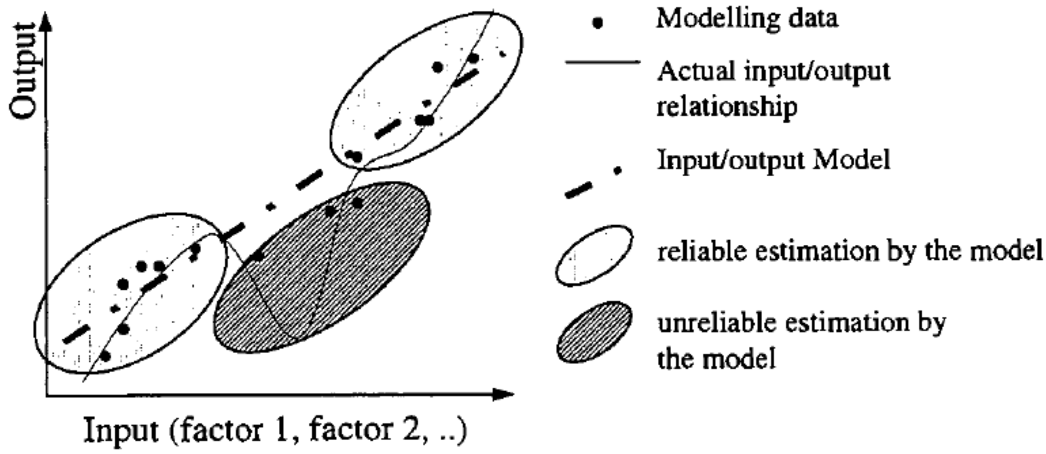


Figure 5. The basic principle and data reliability of the black box following historical data is presented (Annex 25 1995).

The weaknesses and strengths of the black box models are mostly connected to the quality of the training data. Missing data can result to erroneous outputs and make the black box model to be useless. Good data in contrast will result in a model that is robust to noise, is straightforward to use and does not need any deep knowledge concerning the system. Some of the good sides of black boxes can be viewed as negative also. The lack of deep knowledge of the system can lead to difficulties in convincing people to use the complex tool. Simple IF-THEN-ELSE rules are much easier to be confident about, since it is much more difficult to make people trust in a system they do not understand in contrast to a simpler tool that they do understand. (Annex 34 2001). The black boxes are unlikely to prove useful in the commissioning of a new building, since there are no data readily available and the method does not offer any tools of relating the performance to the design expectations. The data would have to come from a different building, which would result in a lot of tuning and adjusting work, unless the building would be identical to the new building. (Peci and Battelle 2003).

Black box models are a natural choice in situations where theoretical models do not exist, are poorly developed or do not explain the encountered performance. Black box methods include statistically derived methods, artificial neural networks and other methods of pattern recognition. Black box models are also suitable in cases where the problems are too complex or intractable to be expressed using any other method even if the physics behind the processes would be well understood. Black box models are a good choice in situations where there are plenty of good training data available or it is inexpensive to create or collect. Black box models can be trained to recognize normal patterns or even really complex patterns and to detect when the patterns chance. Black box models would therefore be useful especially in the buildings with complex HVAC system, controlled by a developed building management systems collecting good data concerning the operation of the system. The physics in such large systems would be too difficult to model and as the patterns would consist of many chancing variables the black boxes would suit be the method of choice. (Annex 25 1995).

7.1.1 **Artificial neural networks (ANN)**

Artificial neural networks (ANN) are a subcategory of the black box methods. ANNs got their name when they were proposed as a modelling method for neurological processes. The ANNs can be viewed as sets of interconnected nodes that are usually connected on several layers, on the input, hidden and output layers (Katipamula and Brambley 2005a) This most common network structure is called the Multi-layer network. Other types of networks include Hopfield network and Boltzmann machine. All of the network structures are presented in the figure 6. Multi-layer networks can be seen as a tool for the numerical modelling of a function, which grants access to the passengers moving between different spaces. (Annex 25 1995). The nodes in the network work as a computational element passing data from one node to another, like can be seen from the figure 6. Artificial neural networks can therefore be seen as a subset of statistical methods, with more complex pattern recognition algorithms than other black box approaches. (Peci and Battelle 2003). The ANNs used for HVAC system diagnostics are typically sigmoidal or radial, based on their network architecture with either supervised or unsupervised learning strategy. (Katipamula and Brambley 2005a).

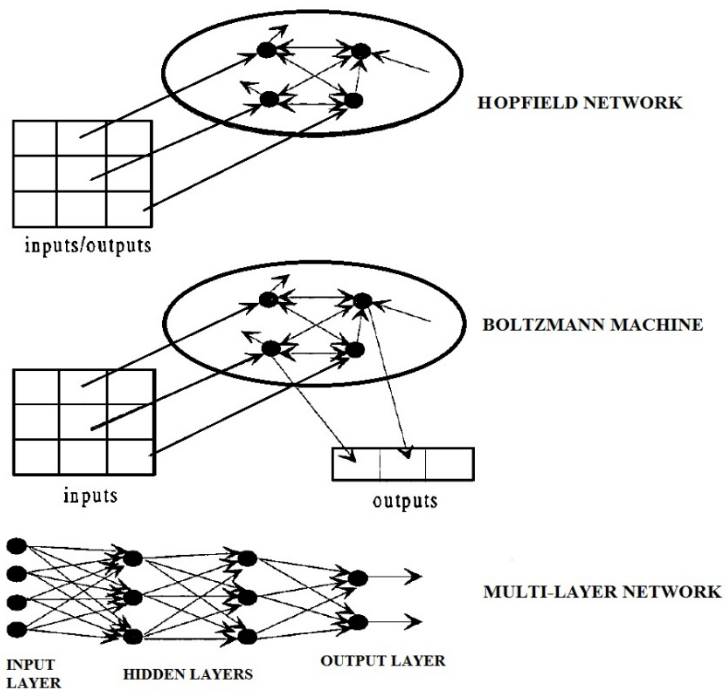


Figure 6. Different types of ANN network architectures (Annex 25 1995).

Artificial neural networks (ANNs) are a statistical black box method, with the advantage that they can model complex functional relationships without detailed knowledge about the physics governing in the system. ANNs can effectively model nonlinear system processes and like other black box approaches they are highly effective in recognizing of even complex patterns. (Katipamula and Brambley 2005a). Another advantage of the artificial neural networks, especially the ones with the multi-layer networks, is their capacity to react correctly to an input which does not belong to the learning basis. In other words, ANNs can interpolate better than traditional black boxes. (Annex 25 1995).

Artificial neural networks are slower to train than other alternative conventional statistical systems because of the complex algorithms they use. Other weaknesses of the ANNs are highly similar than the weaknesses of other black- box systems, adding to them that ANNs are also often considered overkill for building management system analytics. ANNs also do not work well outside the range they were trained and they require large amount of good training data. (Peci and Battelle 2003).

7.1.2 **Statistical methods**

Statistical methods are another subcategory from the black- box methods. There are several statistical methods available today and they are subdivided to parametric and nonparametric methods. Most statistical methods are nonparametric, including cluster analysis, decision trees and other methods that are defined mostly by data. (Peci and Battelle 2003). Nonparametric methods rely on models with arbitrary structures defined by the data that was used to train them. Parametric methods on the other hand include linear and multiple regression as well as polynomial and logistic regression techniques. (Katipamula and Brambley 2005a). Parametric methods are dependent on parametric models in which outputs of the model are expressed as known functions of the model input parameters. Parametric methods are useful in gaining of conceptual understanding of a problem.

The selection of the most potential approach between various statistical methods can be done according to the number of attributes in the system and the intended use. Statistical methods are used in tasks that vary from classification tasks for example, determining if the monitored value is within acceptable values to estimation tasks, for example determining if the AHU is operating at the x% efficiency. (Peci and Battelle 2003). Parametric methods are often considered to be the most potential statistical methods for automatic analysis. A parametric model using first principle knowledge could for example be used to form a model that predicts cooling tower range and approach temperatures based on the knowledge of the normal operation and design information of the cooling tower with measured flow rates and temperatures. A diagnostics tool could then use the difference between the actual and predicted approach temperatures to determine if there is a fault, for example incorrect control sequence or physical error in the cooling tower. Parametric methods can also be trained similarly as the nonparametric methods for extra precision. (Peci and Battelle 2003).

Statistical methods can be used with large data sets and the development methods are well known and documented. Some statistical methods can be used for almost any kind of pattern recognition problems, although considerable statistical expertise is often required for developing the tools using these methods. Parametric methods are normally simpler to develop than the nonparametric methods and they have a tendency to interpolate better than nonparametric methods. Parametric methods represent a classic statistical approach and therefore they are usually well understood and the statistical expertise needed to use the parametric models is often well available. Parametric models offer one of the simplest methods of pattern detection and they are often used in the early stages of projects if there is a need to establish a benchmark of the performance and the more complex methods are either too slow or too costly to use. In the cases where the processes governing in the system are complex and not well understood, nonparametric methods are a more potential choice. (Peci and Battelle 2003).

The weaknesses of the statistical methods are somewhat similar to the weaknesses of other black box systems. All statistical methods require some amounts of good training data to be able to provide meaningful results, and especially the nonparametric methods are depended on the data. Therefore statistical methods do not manage well in the most complex situations where there are not enough good data available and the processes are not well understood. (Peci and Battelle 2003). Despite the weaknesses, statistical methods appear to be well suitable for the use of automatic analysis of BMS. Especially the parametric methods show great promise, because of the ability to tune the model with empirical data from the building alongside the well accessible knowledge of the parametric statistical processes.

7.2 Grey box

Generally it is rare to be strictly based on only theory or only data, therefore most modelling methodologies could be categorized as grey box models, the combination of the data and the measurement based models. Since so many methods use both data and measurements, it would not be the best categorization to call all of them grey boxes. In this work the data models which have parameters, coefficients or other process data determined from measurements, but still have some physical insight by using first-principle physics or engineering knowledge to determine the mathematical form of terms in the model are called the grey box models . (Katipamula and Brambley 2005a). Grey box models usually use linear regression or multiple linear regression models to estimate the parameters of a model from the measured input/output data and at the same time keep the connection to physics in the parameters, which adds physical insight to the model. Grey box models are a combination of a black box model and especially of a simplified physical model, since the physical connection often consists of lumped system parameters with semi-empirical expressions. (Haorong Li 2011). The figure 7 illustrates the development processes and data requirements of physical sub-models, black-box sub-models and grey-box models and the simplification of the ways the models can be combined.

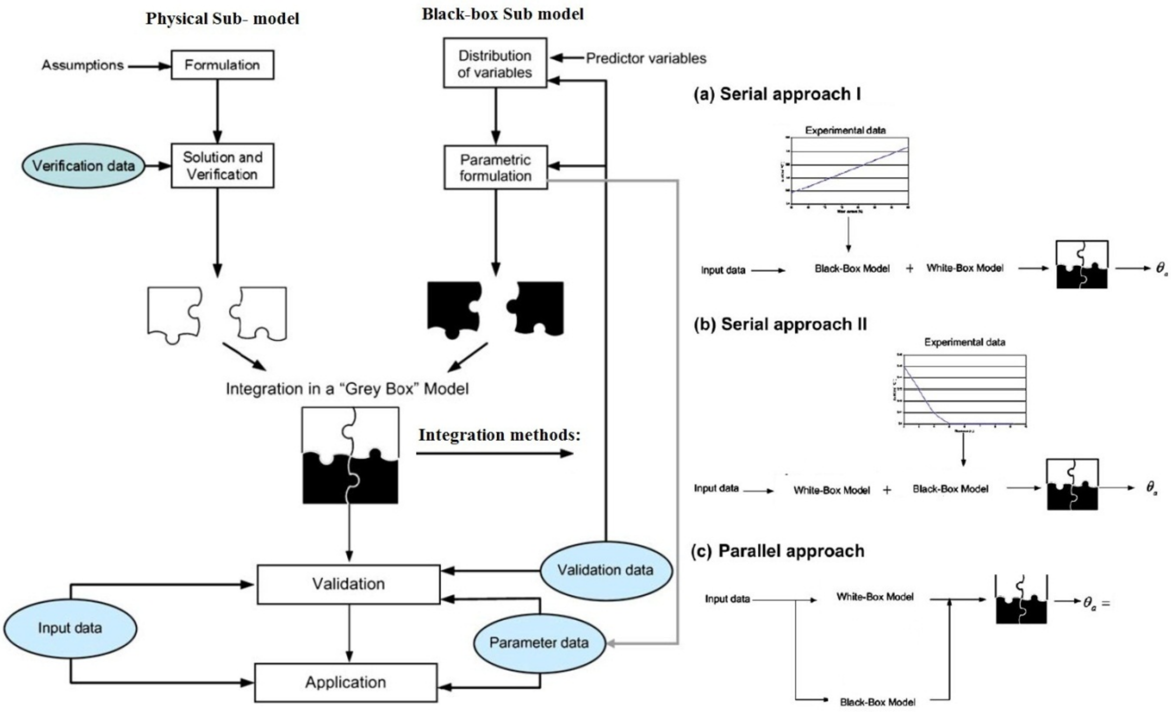


Figure 7. Formulation process of grey boxes can be performed in either serial or parallel arrangements. (Flores 2006).

When physical models and black boxes are combined as grey box models, the aim is to preserve the benefits the both approaches. Grey box models are often preferred over black box models and according to the research by Haorong Li (2011), grey box models have great potential in fault detection and diagnostics applications when compared to physical and black box models. Grey box models usually give more robust parameter estimations than black boxes, providing a better quality for the predictions extracted from the grey box model. Grey box models have a simpler form making them easier to use and also easier to understand, since they have some physical insight added to them. (Katipamula and Brambley 2005a). Grey box models are not as limited in extrapolation as the black boxes, even if the model would be derived from measured data, as the model parameters have been linked to physics. The correlation capabilities of grey box models were shown especially in the research by Jiang and Reddy, who discovered that a certain cooler grey box model developed for a particular cooler provided an excellent fit for varying cooler types. (Jiang and Reddy 2003).

In contrast to the black box models, grey box models are not that easy to formulate. Grey box models require high levels of expertise when putting the model in the right form and forming the appropriate estimations for the parameters in the model. A critical evaluation of simplifying assumptions made in the physical models must also be done.

(Flores 2006). Grey box models also have some problems with the quality of the training data like black boxes, as grey boxes require large amounts of training data also, although the grey box models are not as much dependent on the training as the black box models. With grey box models the errors in the measurements should be minimized as the small uncertainties in the recorded data can lead to proportionately large chances in the physical parameters. (Katipamula and Brambley 2005a).

8 OTHER NOTABLE METHODS

Many of the diagnostic methods presented before are rarely used alone. Many data based and knowledge based methods use several other methods when describing the state of the system and when doing diagnostics. (Katipamula and Brambley 2005a). Especially qualitative methods are popular when doing diagnostics to HVAC systems, since it is difficult to form precise equations describing the complex and often non-linear behaviour of the HVAC equipment. (Peci and Battelle 2003).

Fuzzy logic is not listed under diagnostic methods because it is not an actual source of knowledge. Fuzzy logic is still often used in the field of automatic analysis with the other diagnostic methods. Bond graphs are presented here because they are a combination of the different diagnostic methods providing a unique approach on automatic analysis of BMS.

8.1 Fuzzy logic

The processes inside the HVAC systems are often imprecise and the conditions are often variable and since fuzzy logic is concentrated on describing the uncertainties happening in the process, fuzzy logic is suitable to be used with the automatic analysis of BMS. (Annex 25 1995). Fuzzy logic expresses the uncertainties as fuzzy sets which have no precise value. The values in fuzzy sets are something between true and false. (Peci and Battelle 2003). Especially the different qualitative methods use fuzzy logic for describing the behaviour of the system, because of this more realistic matter of describing the behaviour of the HVAC system. (Annex 25 1995). Many qualitative methods use fuzzy logic also for converting quantitative values into qualitative information. For example water temperatures could be converted to qualitative categories of “too hot”, “warm”, “just right”, “cool” and “too cold” as the boundaries of these parameters are not sharp, fuzzy logic is a suitable tool for the conversion. (Katipamula and Brambley 2005a). Fuzzy logic is most often used with expert systems, where it has been proved to provide a decent theoretical basis and algorithms suitable for describing processes that cannot be adequately handled using classical or Boolean logic. (Peci and Battelle 2003). The easiness of incorporating the expert knowledge using fuzzy logic is other main reason why fuzzy logic is used with the expert systems. (Annex 25 1995). The fuzzy sets that are used with expert systems consist of explicit rules that express the behaviour of the system in linguistic terms. The expert system could for example consist of expert knowledge about what should occur in a situation where temperature rises to a certain level. If there are several different actions depending on the grade of the temperature rise, so that there are no sharp boundaries, fuzzy logic would be a logical choice for this situation. Fuzzy set could be named “Critical temperature” and for example a temperature of 25 decrees could be considered to have a 45% grade of membership of the fuzzy set “Critical temperature”. (Annex 34 2001).

The fuzzy sets that are used with shallow knowledge models, which are formulated most often by training, use implicit fuzzy rules that relate symptoms to faults. (Annex 34 2001). Fuzzy logic gives tools for doing decisions without certainty, for example when doing decisions about whether a condition is wrong or right. Fuzzy logic is also useful tool for reasoning when the information that is available points to a conclusion that is sort of right and sort of wrong. For example in a case when the evidence is pointing that a partially fouled condenser pipes in a cooler increase the static pressure in an air handling unit due to an air filter that is dirty to some extent . (Peci and Battelle 2003). In other words, fuzzy logic offers a systematic approach when doing decisions with “fuzzy” evidence or conditions. (Peci and Battelle 2003).

The biggest advantage of fuzzy logic is its capability to take account for uncertain and nonlinear system behaviour, which is especially useful with HVAC equipment. (Katipamula and Brambley 2005a). Fuzzy logic makes it easier to commission the available expert- and learnt knowledge, which are easily combined and used together with fuzzy logic. Fuzzy logic does not require high levels of computational power making it easier to implement. (Annex 34 2001). The largest weakness or fuzzy logic is the imprecision of the diagnostics it provides, making fuzzy logic useless when diagnosing processes that are vital to the system or in cases where it is important to avoid false positive detections of fault conditions (Annex 34 2001, Peci and Battelle 2003).

8.2 Bond graph method

Bond graph method combines quantitative simplified numerical modelling that is used for designing and analysing engineering systems to qualitative methods which are used for describing complex and non-linear systems. Bond graph method offers tools for modelling different engineering systems, for example mechanical, electrical, hydraulic, and thermal systems in a unified manner. (Borutzky 2009). The bond graph itself is a graph in which nodes represent conservation of energy equations with bonds which are power connections between two parts of the system. (Chiaus 1999). The main idea of bond graphs is bonding the components of the system with power transfer. Bond graph model is the same regardless of whether the components in the model are qualitative or quantitative. For example, to define the connections in a cooler plant consisting of several bound systems, the refrigerant system, the water circuit and the air circuit, Bond graphs has been used to reduce the complexity of the system. Bond graph method in this case also allows a more precise focus on an individual component to form mathematical equations for the individual components, which can later be put together properly to describe the total system . (Borutzky 2009). Setting the boundaries of qualitative variables in the bond graph is a fundamental quantitative aspect of the bond graph approach and it is achieved by the fault detection mechanism. The qualification of measured variables depends on the type and dimensions of the process which is under supervision (Chiaus 1999).

Bond graphs have an interesting approach on fault diagnostics, and there are several advantages in using bond graphs. Bond graph model begins from the simplification and then grows more complex, in contrast to the usual modelling techniques where the first formed complex model is afterwards simplified. The subsystems of bond graph models are easy to solve and they provide visible physical interactions which are easy to follow, which again gives insight understanding of the physical processes in the system. The bond graph method provides effective modelling process, which is unified to all situations. (Chiaus 1999, Borutzky 2009). In the figure 8 there is an example of a Bond graph model made from a simple system with a tank, input and an output.

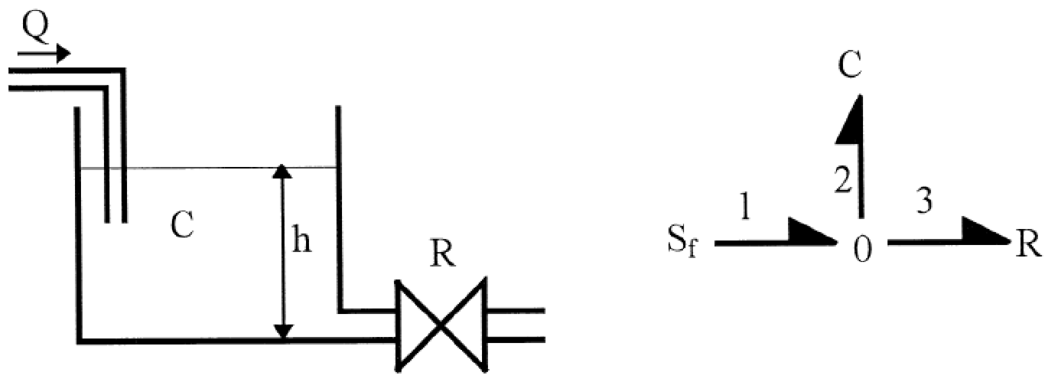


Figure 8. Example Bond graph of a simple system (Chiaus 1999).

Despite of the many advantages, bond graphs have not become common in the systems providing automatic analytics. One clear weakness of the bond graph is the language which is used with the bond graph, as it is written with a specific graphical language which has to be learnt to be able to use the method. Bond graphs can only be used with models with lumped parameters, which limit the usability also. There is either a way to model thermodynamic processes with bond graph which could be one major reason why bond graphs have not become more common than they are now.

9 RISING METHODS

Automatic analysis methods for BMS have appeared widely in the past and they have been largely reviewed in the past chapters. Creating the systems using these methods still remains as a challenge and commercial systems are only beginning to emerge in recent years. (Liang 2007). In this chapter two rising methods for automatic analysis of BMS are presented. The methods are Support vector machines (SVM) and Principle component analysis (PCA). The methods are chosen here, because of the recent research activity that has gained them more attention.

9.1 Principle component analysis (PCA)

Modern HVAC systems are equipped with large amounts of sensors producing great amounts of measurements at high frequency. Principle component analysis (PCA) provides tools for compressing data to reduce data dimensionality so that the essential information is stored and then analysed more easily than the original huge data set. The analytics from the PCA systems are based on the chances and co-variance between variables in the system. The correlations which PCA monitors provide a more useful description of the current process conditions or events than the individual variables that are often monitored by the conventional systems. (Li and Wen 2013).

Principle Component Analysis is a data based analysis method that has gained much attention in the recent years. Conventional data based models for example black boxes or ANNs require faulty training data to be able to recognize any faults. PCA method requires only fault free training data for the model development, which removes the problem of introducing artificial or actual faults to the system only to get faulty data. (Li and Wen 2013). However, although PCA method has been widely used for automatic analysis in the process industry, only a few applications of PCA in HVAC systems have actually been implemented. The main difficulty of applying PCA methods in HVAC area lies in the fact that HVAC systems are highly nonlinear and greatly affected by outdoor and indoor conditions while the PCA systems do not readily work well with the nonlinear processes. To improve the usage of PCA methods with nonlinear processes, certain data pre-processing methods must be implemented. (Li and Wen 2013, Wang and Fu 2006).

The most common data pre-processing techniques are Model library based method, Recursive PCA method (RPCA), and Multi-scale PCA method (MSPCA). (Wang and Fu 2006). The most potential data pre-processing method for the PCA methods is the

MSPCA, which combines the ability of PCA method to "*extract the cross-correlation relationship between the variables with the ability of wavelet transform method to extract the auto-correlation features in the measurements*" (Li and Wen 2013) MSPCA is based on monitoring process measurements in a different time-scale by breaking the measurement data into separate frequency bands. By separating the measurement data, the sensitivity to fault detection increases allowing the detection of the significant events that provide just a little evidence. MSPCA is therefore suitable method to diagnose processes under the influence of slow variations, such as seasonal fluctuations and other long-term dynamics. (Li and Wen 2013). RPCA and model library based method were used together in the research done by Wang and Fu (2006), where the goal was to make the PCA more tolerate to the time variations of air handling units. The approach however proved impractical when implemented to the whole HVAC system, as there were still too much mode and parameter chances in the HVAC system to be handled with the PCA method. There is a flowchart of the methods used in the research in the figure 9. The research revealed also that the constantly changing RPCA model structure makes it difficult to notice faults that develop slowly. (Wang and Fu 2006).

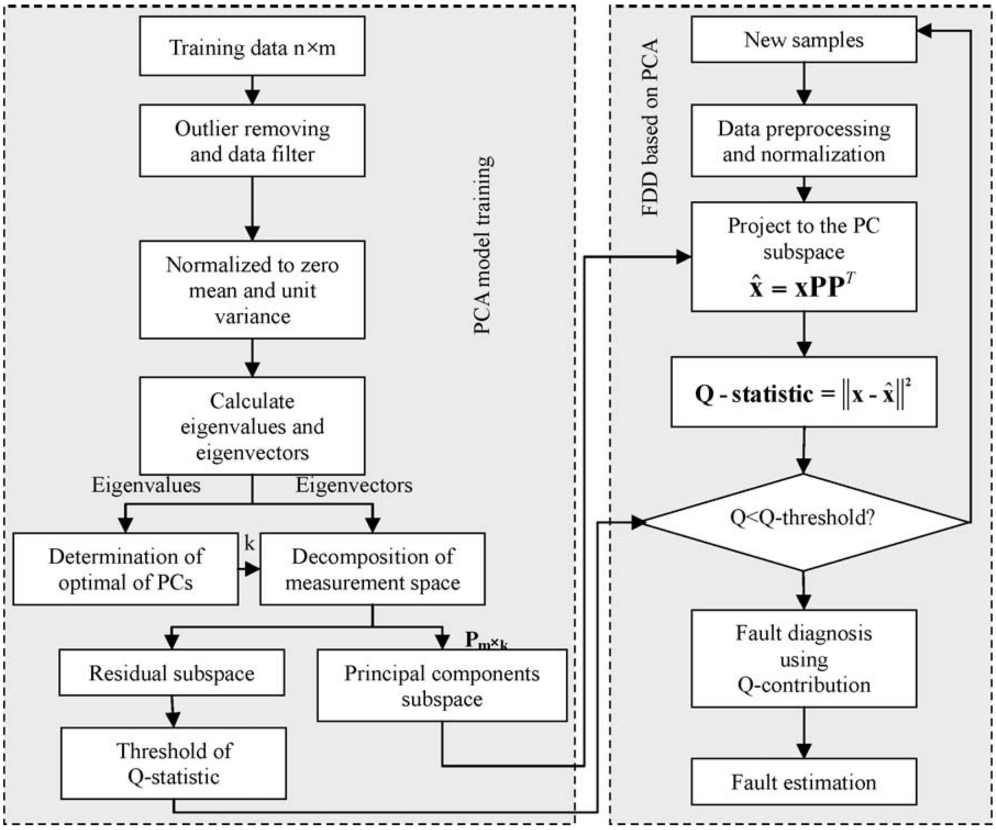


Figure 9. The flowchart of the PCA methods in the research by Wang and Fu (2006), where the goal was to make the method more tolerate to the time variations of air handling units.

9.2 **Support vector machines (SVM)**

Support vector machines (SVM) are a quite new class of machine learning algorithms, but they have been used for fault detection and diagnosis of HVAC systems in several researches, for example in the researches by Shah 2009, Press 2007 and Liang 2007. SVM´s are specifically designed for classification of data. The basic principle of a binary SVM classifier in a case where there is a dataset which consists of two different categories to be classified is as follows: "*The classifier constructs an optimal linear classifier in the form of a hyper plane which has the maximum margin. The margin of a classifier can be defined as the width up to which the boundary can be extended on both sides before it hits one of the data points. The points onto which this margin hits are called the 'Support Vectors'.*"(Shah 2009) The object of the classification is to maximize the separation between the origin and the cluster of normal samples in the feature space belonging to the negative or faulty class. The large separation is wanted because the larger the margin is the lower the generalization error of the classifier drops. The separation is illustrated in the figure 10 as a variable d. (Shah 2009).

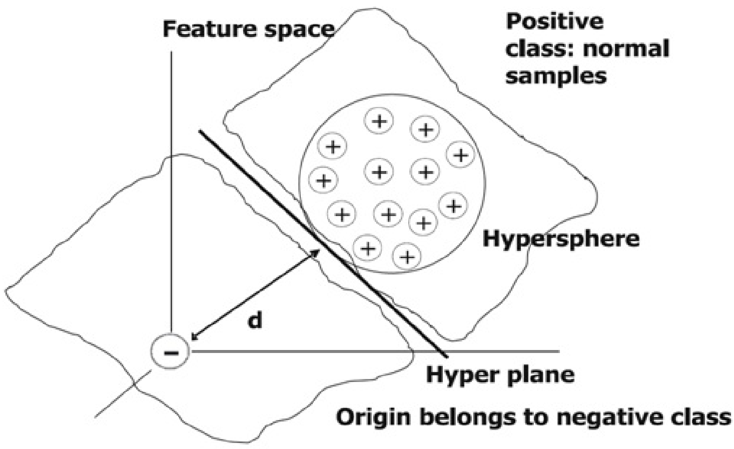


Figure 10. Class 1 Support vector machine (Shah 2009).

When new examples are mapped into the same space with a large margin, the category which they fall on is determined based on the side of the line they fall on. (Press 2007). If the datasets are not linearly separable, the 'kernel trick' is used. With the kernel trick, the original data is mapped into higher dimensional feature space and a linear classifier is constructed in this feature space. This is can be directly compared to constructing a non-linear classifier in the original input space. (Shah 2009).

Generally support vector machines require only small amounts of training data when compared to conventional black box methods, but they still show higher diagnosis accuracy as they are more sensitive to faults than the black boxes. (Liang 2007). The class 1 support vector machines are often used and they have the most advantages, although the sensitivity to faults is reduced to a lower level than for example with PCAs. Class 1 SVM can be used in non-linear cases with the help of kernel tricks, whereas for example

PCA systems are based on linearity assumption and cannot work in nonlinear situations. The class 1 SMVs can also handle multi-modality in their datasets better than the PCA systems. (Shah 2009).

Transition from the methods to the tools

The many diagnostic methods presented before are suitable in different situations and they are all used in the automatic analysis on BMS/HVAC systems. Now that the methods are presented, the next step is to present the different tools using these methods in automatic analysis tasks.

10 TOOLS OFFERING AUTOMATIC ANALYSIS

There are several diagnostic tools capable of automatic detection and diagnosis of energy and other performance problems found from buildings. Many of the tools can prioritize and summarize relevant performance problems, display plots for visualization, and perform automated diagnostic procedures. These tools provide a framework for data management and analysis of the vast amounts of data generated by the many measurements in the system, controlled by the building management systems. The common BMS´s have limited diagnostic capabilities, so there is a great need for tools which would offer automated diagnostics using the BMS data to access the buildings performance. Previous attempts to apply automated analytic methods to buildings have faced numerous problems such as poor integration capabilities, lack of common communication protocols, lack of scalable storage, lack of metadata and lack of diagnostics and analytical tools that could be quickly and cost effectively deployed. (Ulickey et al. 2010). The tools presented in the next chapter have different approaches in overcoming of these problems, but first the basic approaches of the tools are presented.

10.1 Construction approach

The diagnostic tools can be constructed from two different standpoints: the top down approach and the bottom up approach. Tools with a top-down approach rely on whole building energy metering and they usually focus on using real time data. (Ulickey et al. 2010). The starting point in the top down approach is some performance property of a building which describes the function of the entire system, such as energy consumption. The process then moves towards the smaller details. (Annex 25 1995). In most cases, the tools with top down approach do not identify equipment specific faults and the diagnostic capabilities are often limited or non-existent as the building owners and operators are often left troubleshooting the problem independently. (Ulickey et al. 2010). The whole building level analysis normally does not require huge amounts of information regarding the operation of the building and may be applied to buildings with or without sophisticated building management systems. The whole building analysis makes detailed diagnosis and the localization of the reasons difficult but helps make clear the effects of the fault on the system as a whole.

Tools with s bottom-up approach typically rely on the data from the BMS or the building automation system (BAS) for system and equipment specific data and therefore the trended data from the BAS or the BMS become the basis for fault detection. (Ulickey et al. 2010). In the bottom up approach, the process starts with details from the component level and moves towards the consequence of the component problem from the standpoint of the whole system. This component level analysis typically requires a large amount of detailed information and is most useful when used beside sophisticated BMS´s because there are usually a lot of data readily available if a BMS is in use. The component level analysis may include a single system such as an air handler or multiple systems throughout the facility or facilities such as air-handlers, pumps or coolers. Once faults are generated the program may issue a report with diagnostic possibilities for corrective action. (Ulickey et al. 2010). Diagnosing the causes of the detected faults is often simple, but difficulty is found in the number of faults that may occur at any given time. Also the effects of all of the faults on the whole system are difficult to quantify. (Annex 25 1995).

10.2 Business models of the tools

Tools offering automatic analytics have different business models. The research by Ulickey et al. has recognized three main business models, which are presented below. (Ulickey et al. 2010).

The first business model is the model that is used with the business of eService and from the tools which are presented in this work; Infometrics is based on this business model. The service- business model is a traditional service model, where the customer does not see the tool itself, but instead receives reports generated by the tool and then reviewed by service provider acting as a filter. According to the Ulickey research (2010), because an engineer is analysing all data before it gets reported, the tool seems highly accurate. A further advantage according to Ulickey et al is that the site does not need to appoint additional staff to maintain the fault detection system, hence leaving the maintenance staff focusing on resolving issues noted by an outside engineer rather than taking time to first troubleshoot and then resolve an issue. The service- business model is most often based on an on-going cost, where the implementation costs are divided to long time period, lowering the amount of single payment. On the downside the on-going expense for the service is hard to justify if the reported faults lack an energy savings component. (Ulickey et al. 2010).

The second business model is based on sequence of operations, which are programmed directly into the BMS. None of the presented tools exclusively use this business model but PACAR and many common BMS`s offer the possibility of introducing own rules into the system. As the rules are programmed directly into the BMS there is no need for external software making the obtaining of data easier and allowing the usage of the reporting tools provided by the BMS. The probable reason why any of the tools is not completely based on this approach is that although these toolsets are programmed directly into the BMS, installation requires the familiarity with the building and the BMS of the building making the installation time consuming for an outsider. The tools based on this approach also lack support functions so the operation of the tool is often left for the buildings maintenance staff unless someone is staffed to maintain the tool.

The remaining tools PACRAT, WBD and ABCAT all share the third business model, which is software as a service (SaaS). The SaaS approach is a hybrid of service and tool capability. In the SaaS approach the customer is offered an interface to the diagnostics software and the software is just maintained by the tool provider. The software and associated data are usually centrally hosted on the cloud. SaaS is typically accessed by users via a web browser. In some cases, in addition to the cost of installation, there is an on-going fee for software support and, in some cases, fault report generation.

10.3 The most critical features of tools offering automatic analysis

Annex 34 research (2001) presented a criterion on how tools using automated analytics identifying faults and to calculating energy savings could be evaluated. There is however a lack of transparency and standardization in the business as there are no open industry standards guiding the application of the fault detection and analytics methodologies. As a result companies are not sharing much information or details concerning tools or the methodologies inside the tools, as they have had to invest considerable engineering time to develop the methodologies. (Ulickey et al. 2010). Therefore, it is expected that all of the information is not found for every tool, but the evaluation criteria still works great as a guideline of what are the most critical features of the tool.

General	*Sensors*	*Configuration*
What faults can be diagnosed?	*What measurements are needed?*	*What design data are needed?*
What faults can be detected?	*How will sensor accuracy impact the performance of the tool?*	*How many parameters must the user define?*
Under what conditions can these faults be detected and diagnosed?	*At what frequency must data sampling take place?*	*Are training data required? If so, how much and under what conditions should it be collected?*
Does the tool performance depend on operating point, whether or not the system or equipment is operating in steady state, etc.?		

Table 1. A criterion on how tools using automated analytics could be evaluated (Annex 34 2001).

In the following chapters, the most potential tools that are based on different knowledge acquiring techniques and have different approaches for automatic analysis of BMS systems are reviewed. The selected tools have different standpoints on service and on business models. The evaluation criteria presented in this chapter provides a guideline for collecting of the most critical data concerning the tools.

10.4 Automated Building Commissioning Analysis Tool (ABCAT)

Automated Building Commissioning Analysis Tool (ABCAT) is the first tool to be reviewed. ABCAT is built on Microsoft Excel and it is equipped with multiple worksheets, chart sheets, and macros. ABCAT is built with top down approach and it is based on simplified physical model using first principles based mathematical model. ABCAT is designed to be cost effective and simple to use, as the implementation of ABCAT requires measurements from only three sensors; the whole building electricity, the whole building heating and the whole building cooling. The needed measurements are illustrated in the figure 11. All of the required sensors are often readily available in the buildings and if not, they are inexpensive and simple to install. (Bynum et al. 2012).

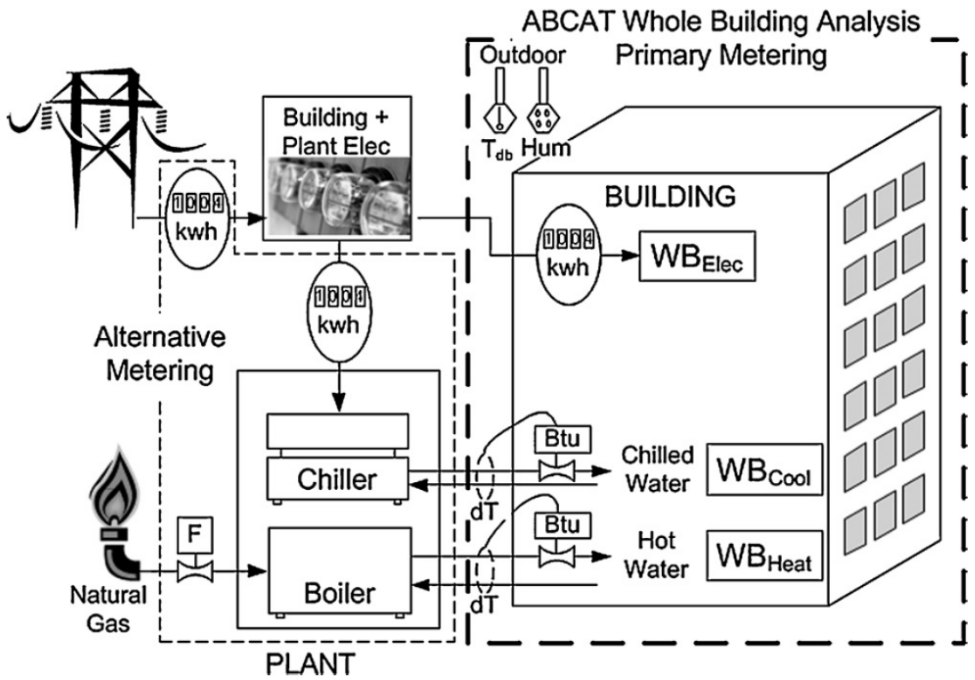


Figure 11. The three sensors required by ABCAT, WB_{Elec}, WB_{Cool} and WB_{Heat}, are presented (Bynum et al. 2012).

The aim of ABCAT is to predict the energy consumption of a building under constantly changing weather conditions. The measured consumptions from all of the three sensors are compared to the predicted energy consumption and the possible faults are detected based on statistically significant difference between the two data sets. ABCAT focuses especially on detecting the persisting faults that have the biggest impact on the energy consumption as the fault detection methodology focuses on the cumulative effects of faults. After a fault is detected, the simulated and measured energy consumption is presented graphically to provide instruments to diagnose the faults. The most important graph presented by the ABCAT is the cumulative energy difference plot shown in the figure 12. In this plot, the daily difference between the measured and simulated consumption of the previous day are added to the cumulative difference from previous days cooling and heating. The cooling chilled water is marked as CHW and the hot water for heating from the central plant is marked as HW. (Bynum et al. 2012).

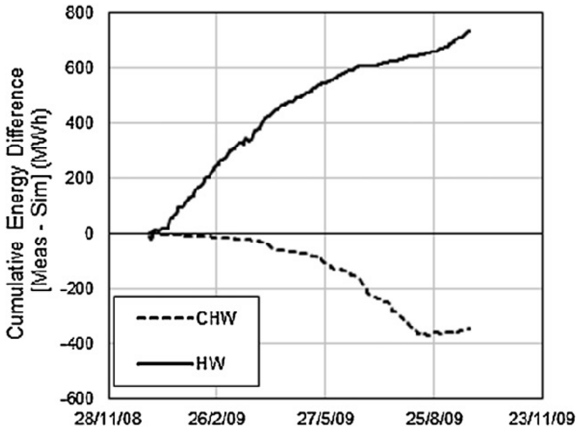


Figure 12. Example of the cumulative energy difference plot. The graphs are named Chilled water for cooling (CHW) and hot water for heating (HW) (Bynum et al. 2012).

Providing the costs in an easily understandable form, which is simply the energy difference, multiplied by the cost of the wasted energy, is expected to increase the user activity to take action when faults are detected. (Bynum et al. 2012). The cumulative energy difference plots are proven to be successful in identifying three major consumption deviations in the four live test building implementations. The cumulative energy difference plots are useful in visual presentation of the buildings energy consumption performance, but to be able to use this data for automatic analysis, two more steps, which are shown in the figure 13 as steps from 4 to 5, have to be executed. (Bynum et al. 2012).

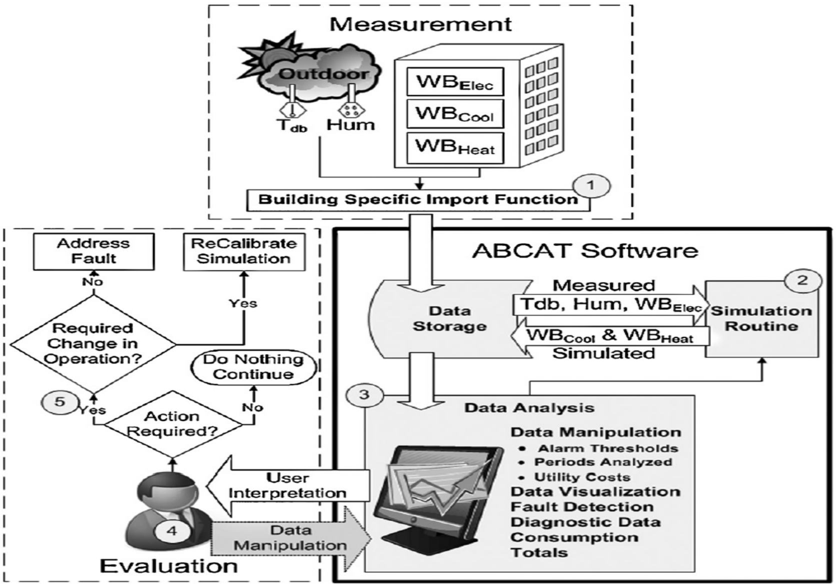


Figure 13. The five steps of the ABCAT process (Bynum et al. 2012).

ABCAT process consists of five different steps and of a calibration process. The first step is the importing of the measured weather and energy consumption data to the system. In the second step the energy consumption of heating and cooling are simulated using the measured data and a calibrated mathematical model. (Bynum et al. 2012). The calibration process is carried out manually by iterative process of alternating the building parameters until the model matches the actual consumptions. The calibration process can be time consuming and requires a great deal of specialized expertise. The steps of ABCAT calibration process are presented in the figure 14. (Hissel 2012).

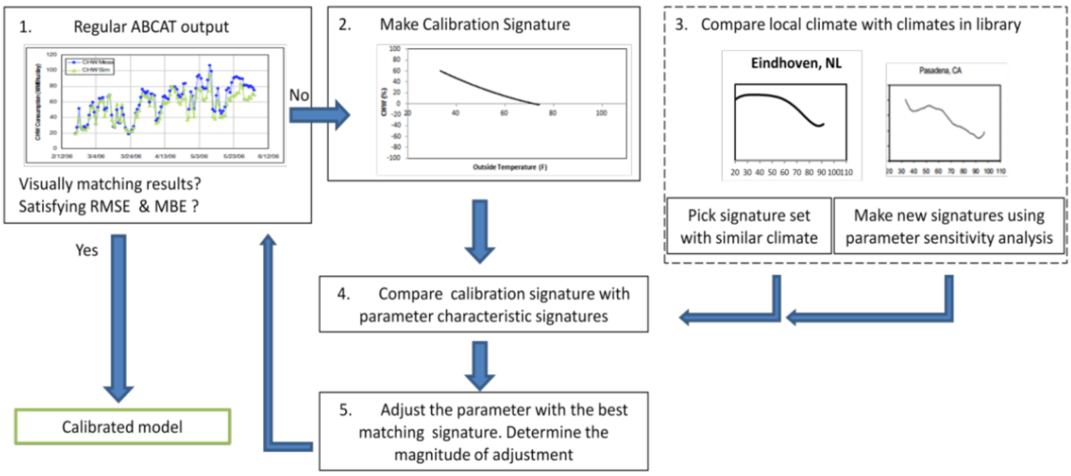


Figure 14. The ABCAT calibration process (Hissel 2012).

In the third step the simulated and measured consumption data are analysed and data visualizations are made automatically using the plots presented in the figure 10. The fourth step consists of a user made evaluation based on the analysis in step 3, regarding whether there are faults present or not or if the faults require action or not. If there were faults that require action present, the final step is reached and the reason of the change in consumption is determined. If the chance is seen to be a result of a required change in the buildings operation, the ABCAT simulation is recalibrated for the further application of the tool. However if the change in consumption is not a result of a required change in the buildings operation, the user must diagnose the fault using the provided diagnostic information and the users own experience. (Bynum et al. 2012).

The results from the ABCAT implementations in the USA are shown in the table 2. During the tests, ABCAT was capable of finding several problems in the systems it was implemented and the savings from the fixed problems varied from 9500 to 29000 $. According to the results presented in the research done by Bynum et al. the ABCAT was found capable of detecting especially long term problems. The simplified approach of ABCAT was found easy to use and it proved to be robust, although the research by Hissel (2012) revealed that the automated diagnostic capabilities and calibration process of ABCAT must be developed, as they depend too much on the experience and the knowledge of the user.

University dining facility 7600 m2 USA	Mar 2005– July 2007	ABCAT detected a fault resulting to excess cooling rate related to excessive latent cooling from low discharge air temperature on 2 of 3 Outside Air Handling units in the summer 2006. Increase estimated to cost $9500 during fault period
Computing services facility 44,700 m2 USA	May 2005– July 2007	ABCAT detected a significant decrease in measured cooling energy due to meter calibration in Oct 2005 Significant excess cooling energy was detected by ABCAT in Nov 2006. Increase estimated to waste 29 000 $ during fault period

Table 2. The top results from ABCAT implementations (Bynum et al. 2012).

10.5 Performance and Continuous Re-Commissioning Analysis Tool (PACRAT)

Performance and Continuous Re-Commissioning Analysis Tool (PACRAT) developed by Facility Dynamics Engineering is a complex data based tool using a black box and a multiple variable bin method (Bynum et al. 2012) with expert rules which are based on the first principles. PACRAT assesses the HVAC system operation and digs into the root causes of problems. PACRAT summarizes relevant performance characteristics and targets repairs to the most costly problems. PACRAT utilizes both top-down and bottom up approach. The top-down approach is implemented in the baseline of historical energy use for whole building energy. The bottom-up approach is the main approach of PACRAT. The bottom- up approach shows in the sub metering of components and in the diagnostic capabilities of PACRAT, which specifically focus on pinpointing system problems. PACRAT identifies problem states, which it calls anomalies, and provides possible causes and resolutions by utilizing the data that has been recorded and stored by the BMS, energy metering system or any other data source. PACRAT links the anomalies directly to time-series graphs (Friedman and Piette 2001) which are based on a database that utilizes recorded system operational trend data to be used for analysis. The anomalies are presented with anomaly forms, of which there is an example in figure 15. PACRAT calculates cost waste for each data collection interval, then sums the cost waste over time. The user can then compare cost waste across different system levels. The logic tree in the diagnostic tool is proprietary, so the methods cannot be evaluated externally, as can be seen from the figure 15 (Friedman and Piette 2001).

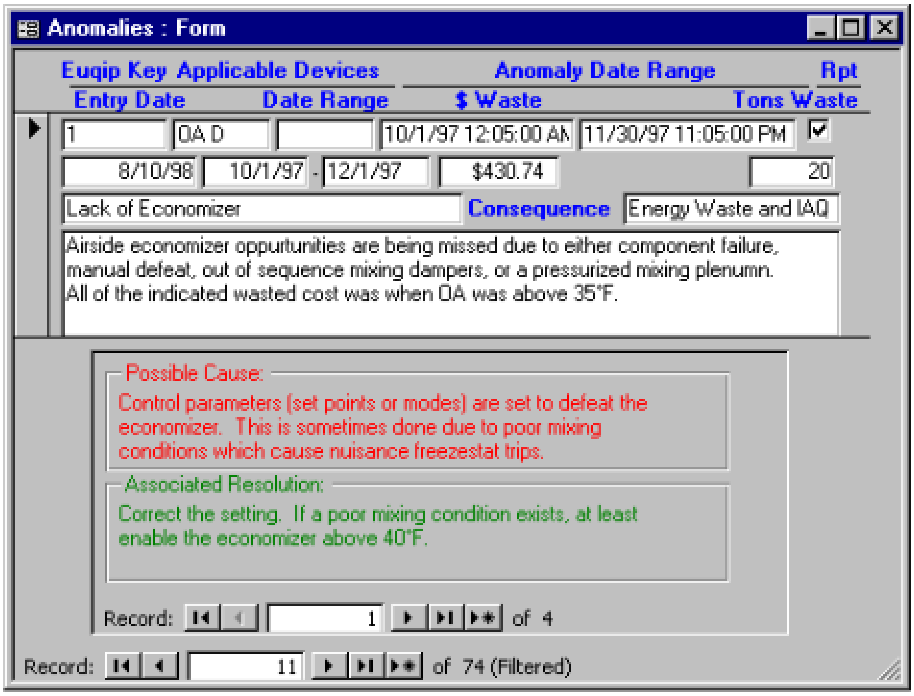


Figure 15. PACRAT anomaly form (Friedman and Piette 2001).

PACRAT characterizes actual system performance and operating/space parameters so that the future assessments of space requirements can be based on fact, rather than on good guesses. For example when planning on an expansion PACRAT can offer information about if extra coolers are required or not. PACRAT can also be used for data visualization allowing the operation personnel to better understand how the facility operates. Operating personnel can observe the buildings operation and be aware of possible performance inefficiencies allowing them to make more informed decisions. (PACRAT overview). PACRAT identifies the wasted energy caused by the inefficiencies or faults and can diagnose the reasons for them and in also offer suggestions of how to fix the problem. PACRAT is also a metering, verification and measuring tool that can combine measured data with actual or virtual meters to benchmark energy performance or present and analyse utility data. (Santos et al. 2000).

PACRAT consists of three modules:

1. **Snatcher** module, which is used for data collection
2. **Expert** module, which is used for analysis and diagnosis
3. **Viewer** module, which works as a user interface

The Snatcher module connects to the BMS or the logging system and creates trend logs of the appropriate data on a local server. The data are downloaded periodically and converted to PACRAT form. The Expert module is then used for data analysis. After the Expert module has completed the analytics and diagnostics, it passes the processed information on to the Viewer. The Viewer prioritizes the findings to list of suggested repairs according to the estimated energy waste. Along with fault detecting and reporting, PACRAT can meter energy use to maintain two running baselines for before and after comparison of savings based on current utility rate schedules. Users are provided with a real time reading of energy and unrealized energy savings. (PACRAT overview).

PACRAT offers several different diagnostics, of which some are presented in the figure 16. PACRAT's automated diagnostics address the air handlers, coolers, hydronic system, whole building energy, and zone distribution. Besides doing diagnostics, PACRAT also offers fully customizable prioritizing table and it can indicate the consequences of detected problems. (PACRAT overview).

- Leaking Valves and associated wasted cost and false load
- Out of sequence coils and associated wasted cost and false load
- Unoccupied period operation (fan and ventilation) and associated wasted cost
- Inadequate ventilation rates along with the associated parameter statistics
- Excess outside air flow along with associated wasted cost.
- Missed free cooling opportunities (lack of economizer) and associated wasted cost
- Deviations from defined set-point and/or profile ranges
- Unstable control
- Degrading heat exchange surfaces
- Inefficient chiller sequencing
- Poor Efficiency
- Excessive Cycling
- Low temperature difference in decoupled hydronic systems
- Excess energy use from defined baseline

Figure 16. PACRAT examples of available diagnostics (PACRAT overview).

PACRAT can be applied to a site server or remotely to an internet server and the architecture is chosen depending on the implementation method. If the PACRAT is implemented to a site server, there has to be a direct connection to the BMS system so that the PACRAT snatcher can access the data. The computational requirements are quite low at today's standards, as the recommendations state that at least 1 GB storage space and a processor with at least 128 MB of RAM memory are required. The Internet server offered for PACRAT implementation is a more modern choice than the implementation on a local server. With the internet server, there is no need for a server computer, since the PACRAT snatcher accesses the BMS via internet and PIMp module, which comes with the internet server, then sends the information across internet. PACRAT can then be accessed with an internet browser accessing remote client. The computational requirements are even lower than with the local server, demanding a minimum of 64 MB of RAM memory capacity from the processor. (PACRAT overview).

PACRAT uses expert rules extensively to assess HVAC system performance. Any other of the reviewed tools does not use them as extensively, although PACRAT lacks transparency in its methods, since the expert rules have not been published. (Friedman and Piette 2001). Over fifty problems can be detected for of which some have examples in the figure 13. PACRAT has a multiple variable baseline model, which can be used for any data point, which provides the tools user a good amount of data to go through. PACRAT reports deviations from baseline operation and estimates the wasted costs.

The points are arranged hierarchically providing effectiveness in viewing of the performance metrics. PACRAT can periodically assess system performance and help prioritize maintenance as the tool shows cumulative cost waste over time. (Friedman and Piette 2001).

PACRAT has a well-developed graphical interface and it uses commonly available sensors. PACRAT is also a mature tool, so most of the programming errors have been already fixed. PACRAT is an extremely heavy tool and the costs for the implementation range from 10 000 to 30000 $ because of the training that is included in the price. PACRAT requires commitment by building staff to help gather system information for the configuration process, as the process tends dig into more operation details. (Friedman and Piette 2001). PACRAT uses only batch files, so it does not have any real- time data using capabilities. PACRAT has been documented to be used in a few buildings and the results from the PACRAT implementations in are shown in the table 2. (Santos and Rutt 2001).

10.6 Whole Building Diagnostician (WBD)

Whole Building Diagnostician (WBD) developed by Pacific Northwest National Laboratory (PNNL), is an automated diagnostics tool utilizing BMS data collected by direct-digital control (DDC) systems. WBD consists of four main modules: the two diagnostic modules: the Outdoor-Air/Economizer module and the whole building energy module and then the user interface, and a database which stores measured data, as well as diagnostic results. The modules are connected by an infrastructure connected to buildings BMS, which provides data transfer, data management, and process control. (Bauman and Hail 2003). WBD's Outdoor-Air/Economizer module diagnoses whether each air handler in a building is supplying the designed amount of outdoor air for the occupants, by time of day and day of week. The module also determines whether the economizer is providing free cooling with outdoor air when appropriate, so that the energy is not wasted by supplying excess outdoor air to the air handling system. The Whole-Building Efficiency module monitors whole-building or subsystem performance at high levels. Therefore the WBD has both the top down approach with the whole building efficiency module and the bottom up approach with the Outdoor-Air/Economizer module. The Whole-Building Efficiency module tracks the actual energy consumption and compares it to the estimated expected consumption. The expected consumption is calculated based on an internal empirical model that takes into account factors such as time of day and weather. The module then automatically constructs a model based on the past system consumptions forming a baseline of performance. The model then alerts the user if the performance deteriorates. The model also informs the user when the performance has improved due to fixes implemented to the system, sequence chances or other possible improvements. The structure of WBD is clarified in the figure 17. (Bauman and Hail 2003).

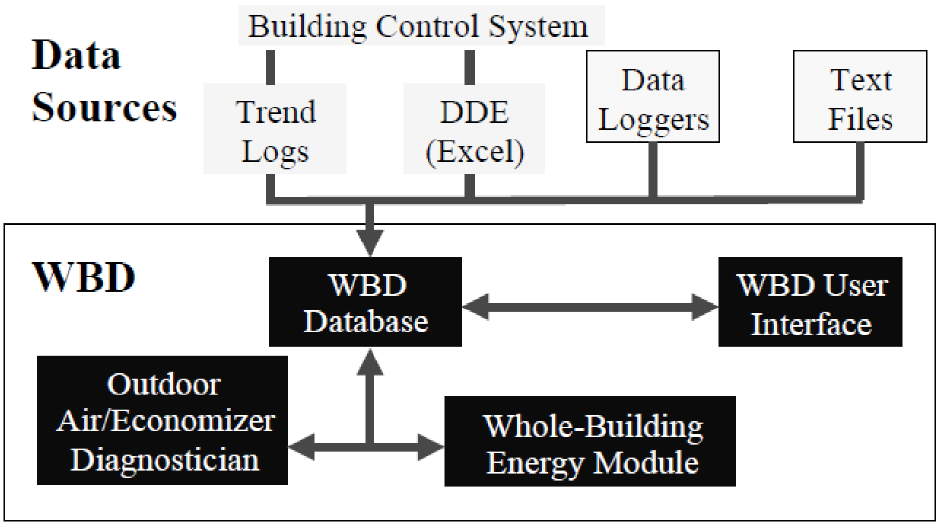


Figure 17. The structure of the WBD tool (Bauman and Hail 2003).

WBD's Outdoor-Air/Economizer module has several different diagnostic methods implemented. Outdoor-Air/Economizer uses rules derived from engineering models and expert knowledge of proper and improper air-handler performance to diagnose operating conditions. (Pratt et al. 2002). The module uses physical rules and statistical methods to detect problems and expert rules to diagnose their cause. WBD's decision tree includes twenty different diagnostic end states. An example of the states and decision trees implemented in the Outdoor-Air/Economizer is presented in the figure 18. The logic tree uses qualitative rules based on first-principles and statistical methods for problem detection. (Katipamula et al. 1999). WBD also uses artificial neural networks to predict the building energy consumption based on weather and calendar conditions. (Dodier 1999).

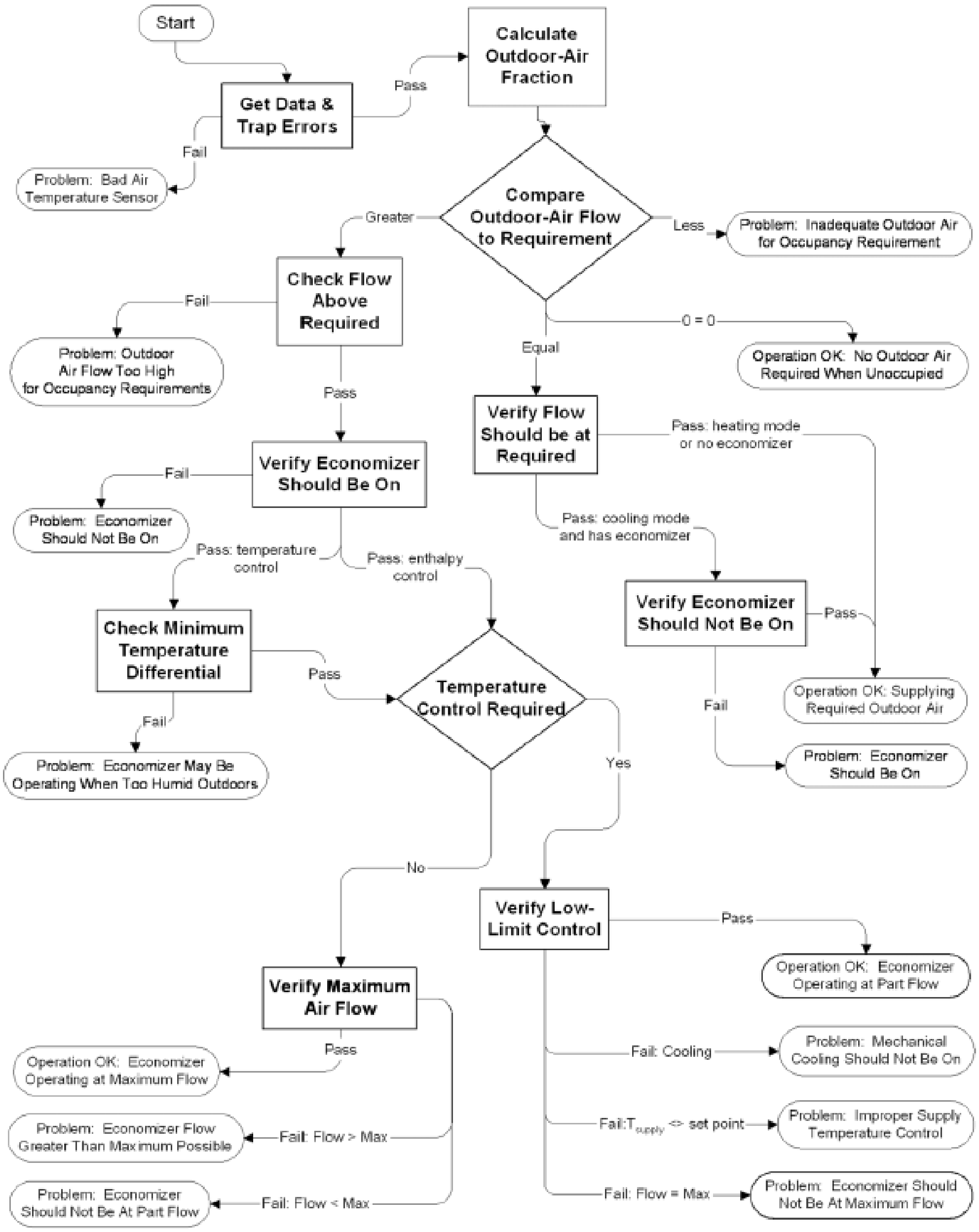


Figure 18. The states and rules of the Outdoor-Air/Economizer (Katipamula and Brambley 2005a).

WBD has been designed for operators with a little time or skill to interpret any time series data, so no raw data visualization functions are included. Therefore communication of diagnostic results without requiring interpretation of diagnostic plots is implemented. (Friedman and Piette 2001). The tool relies on a colour map which notifies the user of problems and classifies the problems to three different classes, “ventilation low”, “high energy” and “other”. The “high energy” cell is displayed both when the economizer should be fully open but is partially or fully closed and when the economizer should be at minimum position but is open. (Friedman and Piette 2001). There are classes also for system ok and incomplete or no diagnosis. The map includes columns for each day and the display range can be chosen from one week to one year of hourly data. The columns are divided into rows for each hour. The colour map visualizing the hourly diagnostic results allows users to get a basic understanding of the state of the system with one glance. The cells in the colour map are linked to lists of possible causes, remedial actions, and the temperatures used in the calculation of outdoor air fraction for that hour. Figure 19 shows an example of the colour map where there is evidently a high energy consumption problem and a lot of other problems in the system. (Katipamula et al. 2003). The arrow in the figure 19 points out the cell from which the figure 20 has description of the diagnosis, impacts and possible causes of the problem and a suggestion how to fix the situation. Each cell in the map represents an hour. In the figure 20 there is also a separate "details" box showing, which gives a more precise explanation of the problem.

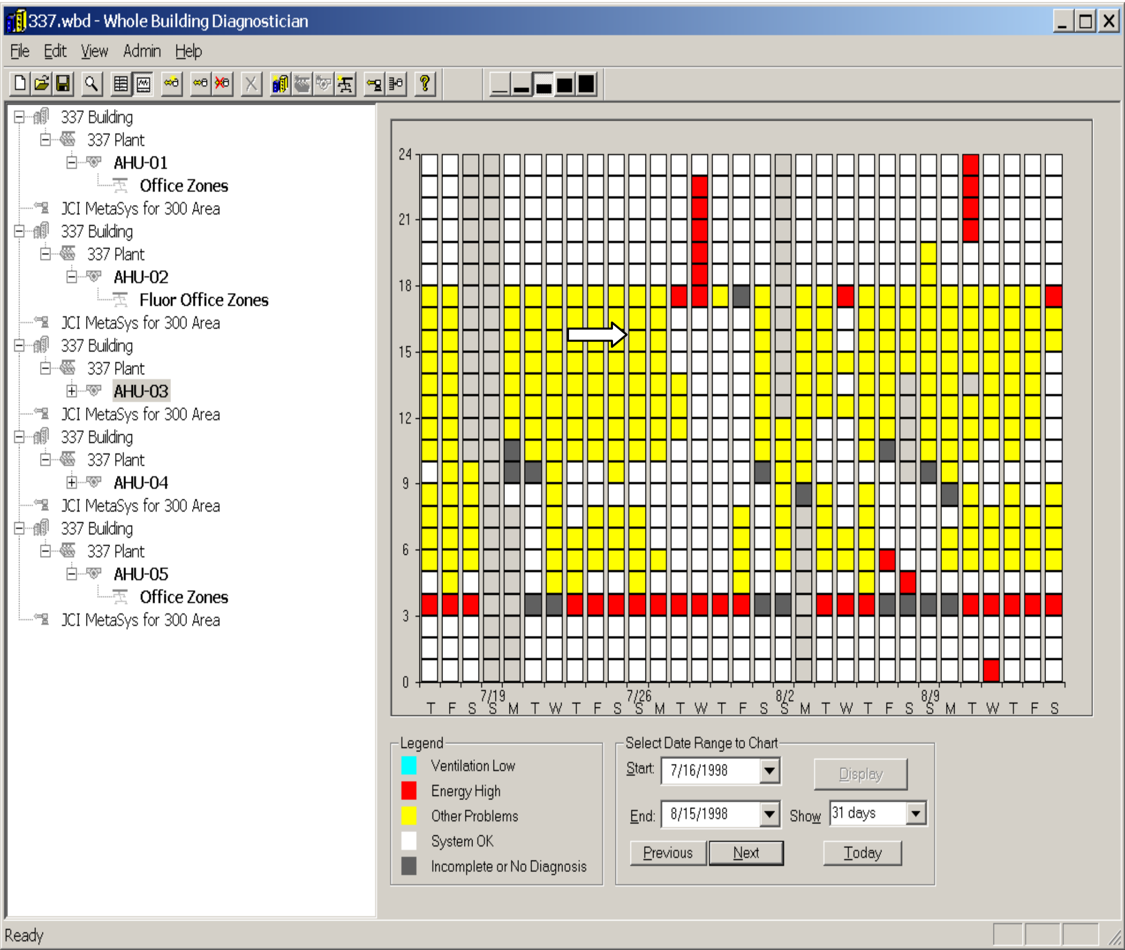


Figure 19. An example of the WBD colour map (Katipamula et al. 2003).

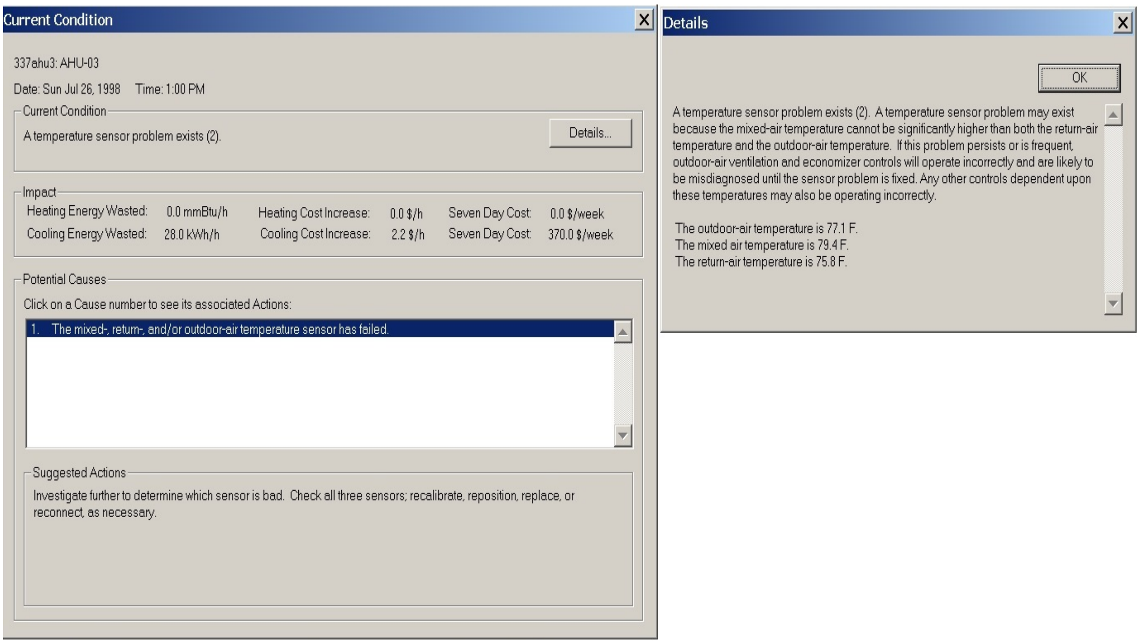


Figure 20. The diagnosis, impacts, possible causes and possible fixes of the problem that was pointed out in the figure 19. The separate "details" box gives a more precise explanation of the problem (Katipamula et al. 2003).

The data for WBD is obtained using a 5-15 minute polling frequency and is then used for calculating of hourly averages. The use of average hourly dampens any spikes in energy and temperature, which reduces false diagnoses that might occur due to data collection problems. The negative consequence is that it also reduces the ability to detect peaks in energy usage or control that are oscillating randomly. (Friedman and Piette 2001). Few, if any, sensors other than those used to control most economizers are required for implementing the WBD modules, WBD also does not try to find all the problems in the system, like for example PACRAT, but instead it focuses on a few specific system diagnostics. These features make the WBD cost effective as a few if any new hardware are needed and the instalment of the software is not time consuming. WBD judges whether a conclusion is significant based on an estimate of the probability. To make the diagnostics more precise, there are five pre-defined sensitivity settings in the diagnostic tree that assign tolerances to all measurements and then propagate the uncertainty through the evaluation of rules. (Friedman and Piette 2001, Pratt et al. 2002).

WBD and the OA/E module were shown to successfully identify a number of major problems with the air handlers at FAA and at the symphony towers. The findings from the both implementations were consistent with the other field demonstrations of the WBD. In both implementations in both implementations many of the findings were left unfixed so the full potential was not achieved. Therefore it became clear that the diagnostic technologies alone will not result in system efficiency improvements. Improvements can only be realized in the buildings where identified problems are corrected. The demonstration showed that diagnostic technology is only as good as the fixes to the problems it identifies. (Pratt et al. 2002). The results from the implementations can be seen from the table 3 below.

Two buildings at the Federal Aviation Administration's (FAA's) Denver airport site 3 air handlers 8500 m2	2000-2001	WBD and the OA/E module were shown to successfully identify a number of major problems with the air handlers The overall annual savings for the air handlers were estimated to be from \$750 to \$1750
the Symphony Towers in San Diego 4 air handlers 55, 000 m2 PNNL-14239	2000-2002	Problems with all four AHUs were identified The savings were estimated from one air handler only, because in the other three, there were faulty sensors The estimated annual cooling energy savings from correcting the problem found by WBD were 81,000 kWh with a corresponding value of about \$12,200

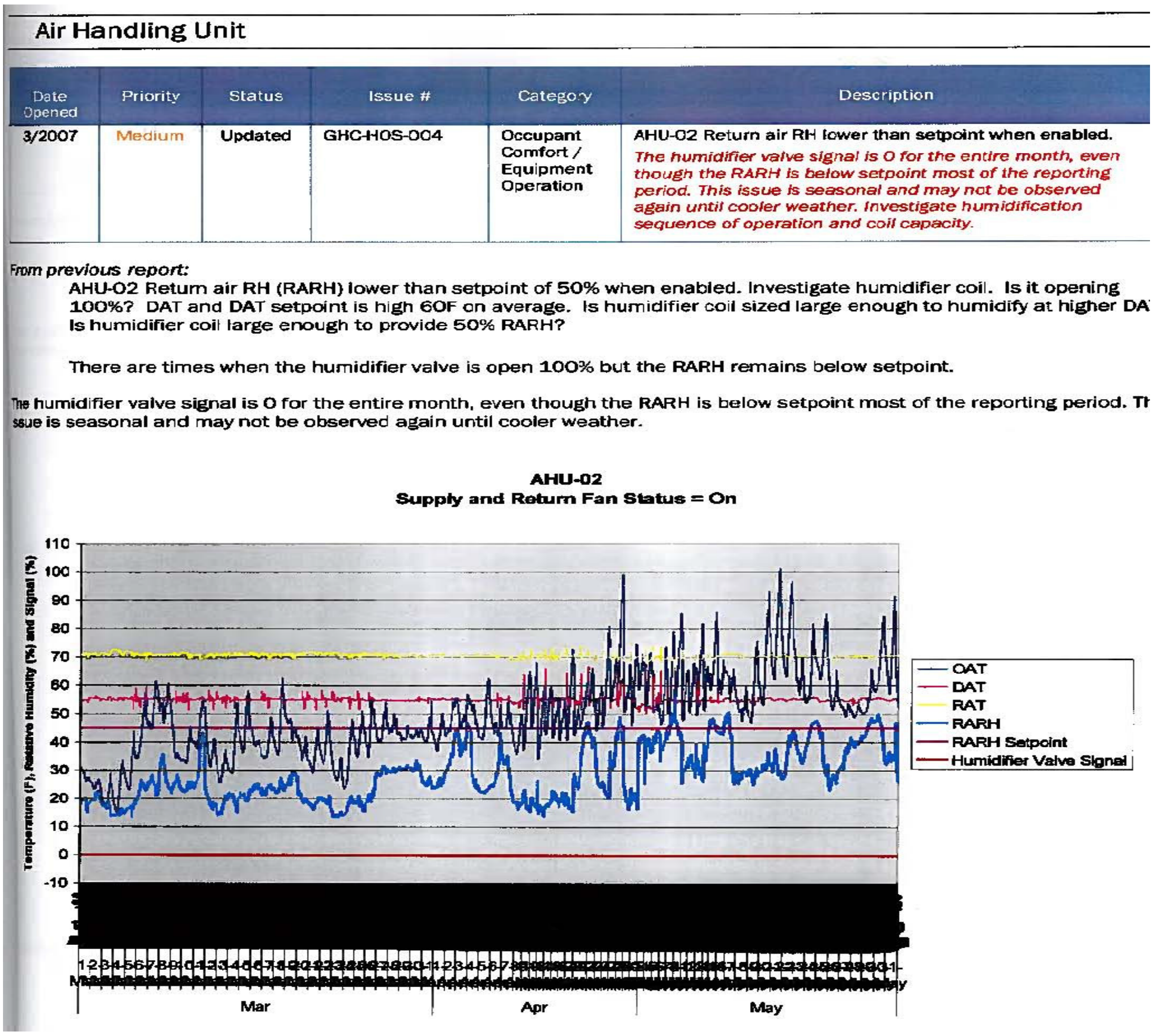
Table 3. The WBD implementations (Pratt et al. 2002).

10.7 **Infometrics**

Cimetrics, the leading supplier of BACnet technology, is a Boston-based company that provides automatic analysis, diagnostics and reporting to building operators with a tool called Infometrics. (Lee et al. 2007). Infometrics is a unique tool in the sense that it is purely service based and therefore there is no software offered for the customer. The data is analysed and all the reports are reviewed by a Cimetrics worker before anything is sent to the customer. The worker therefore acts as a filter providing the customer with only relevant and accurate reports. (Ulickey et al. 2010). The advantage of using Infometrics is that a site does not need additional staff resources to maintain the fault detection system and the existing operator staff can focus on resolving issues noted by an outside engineer. A potential down-side of Infometrics pure service model could be the on-going expense for the service, especially if the noticed problems do not produce savings when fixed. (Ulickey et al. 2010).

Infometrics has a clear process. At first, one year's worth of utility bills and a points list from the building´s BMS are gathered and then a proposal is generated for the site. The proposal includes the costs from connecting to the site and from the monitoring (Ulickey et al. 2010). If the customer still shows interest, the site BMS is reached via

Cimetrics cache- poller and all the needed data are transferred to the Cimetrics servers. When all the needed data are gathered, the data monitoring starts. The diagnostics and other reports of Infometrics are monitored daily, year round and the most critical problems and potential additional energy savings are written up and reported in the anomaly report at an interval specified by contract. The anomaly report includes diagnostics and recommended solutions. (Ulickey et al. 2010). There is a sample report in the figure 21, revealing the content of the reports in more detail.



Air Handling Unit

Date Opened	Priority	Status	Issue #	Category	Description
3/2007	Medium	Updated	GHC-HOS-004	Occupant Comfort / Equipment Operation	AHU-02 Return air RH lower than setpoint when enabled. *The humidifier valve signal is 0 for the entire month, even though the RARH is below setpoint most of the reporting period. This issue is seasonal and may not be observed again until cooler weather. Investigate humidification sequence of operation and coil capacity.*

From previous report:
AHU-02 Return air RH (RARH) lower than setpoint of 50% when enabled. Investigate humidifier coil. Is it opening 100%? DAT and DAT setpoint is high 60F on average. Is humidifier coil sized large enough to humidify at higher DA
Is humidifier coil large enough to provide 50% RARH?

There are times when the humidifier valve is open 100% but the RARH remains below setpoint.

The humidifier valve signal is 0 for the entire month, even though the RARH is below setpoint most of the reporting period. Th
ssue is seasonal and may not be observed again until cooler weather.

Figure 21. Infometrics example report (Ulickey et al. 2010).

There is little technical information available concerning the Infometrics processes, as the tool is quite new. The interview of the Cimetrics CEO (Sinclair 2012) showed to be the best and only source of technical information from Infometrics: The approach of Infometrics is bottom up as the Infometrics focuses to problems in individual HVAC machines. Infometrics has a rule based diagnostics machine, which has scalable data collecting algorithms capable of collecting data from wide range of building automation systems. The raw data is run through algorithms and cleansed to prepare it for the diagnostics. (Sinclair 2012).

One site using Infometrics tool was interviewed in the Ulickey et al. 2010 research and the customer had found the diagnostics provided by Infometrics nearly 100% accurate. The actual rate of diagnostics is however unknown as the customer only sees the reports that are foreseen by a Cimetrics worker. With the site, the report was issued monthly initially, but dropped to quarterly once savings were realized. In the first year the service paid for itself, but however in the following years, according to the customer, the on-going fee was difficult to justify to as the savings decreased when the biggest problems were fixed.

11 SERVICE MANAGEMENT THEORIES

One of the main concepts in this work is the analysis concerning the implementation of the tool under research to the work of eService. The work of eService is centred on providing service, so in order to be able to evaluate the effects of the tool under research to the service the service quality of eService, one must recognize what elements there are in the service business. In this chapter, the backgrounds of the service management are discussed an introduction to service management is provided and the base for evaluating the development of the service of eService is created.

Service management is concerned about the delivery of service to the customers. Service management involves understanding the needs of the consumer, managing the processes and methods used in providing of those services while maintaining a commitment to continuous improvement of services. Service Management is the foundation to organizational management and as such is a critical component to organizational success.

During the last several decades there has been major activity concerning the transformation from producing output to offering services. Many leading edge firms and researchers have found that competitive advantage can be enhanced through service. (Davies 2003). Therefore there is a major need of focusing the orientation of firms towards a more service oriented state. Including more services in the total offerings of firms has several economic advantages: It is said to improve the sales of goods as the respond to demand improves. Also the services generally have higher margins than products (The Economist 2000) and services provide a more stable source of revenue as they are resistant to the economic cycles that drive investment and equipment purchases. (Oliva and Kallenberg 2003). Including more services in the total offerings is said also to lengthen customer relationships and create growth opportunities in already mature markets. (Davies 2003). Services are also less visible and more labour dependent and therefore much more difficult to copy, thus becoming a sustainable source of competitive advantage. (Oliva and Kallenberg 2003).

11.1 Background of service management

The separating four features of goods and services (inseparability of production and consumption, heterogeneity, inventoriability, and perishability) were first recognized in 1985 by Zeithaml, Parasuraman, & Berry. Since then the academic service management has continued to guide firms toward producing and developing services with not much difference to the producing and developing of goods. The logic that emerged from those foundations is called Goods- dominant (G-D) logic. Goods dominant logic, focusing on the differences between the goods and the services, suggests that moving from manufacturing business to service business requires a change in the unit of output from the tangible to the intangible and a modification of production and distribution practices to deal with the differences between tangible goods and services. According to Vargo and Luch (2004, 2008) this is a logic that not only misleads “goods” firms, but one that has misled what are traditionally thought of as service industries (e.g., airlines, banks, healthcare, education, government) toward trying to refine the production of units of services and away from providing service. Vargo and Luch (2004), backed to most extent by many other researches (Grönroos 2006, Gummesson 2008), argue that there has been a hole in the understanding in the concept of “service” and its role in exchange and competition. The research by Brax (2005) also backs up the claim, as the research comes to a conclusion that the “implicit transaction-oriented business philosophy of the manufacturer does not support service offerings”. Common thought of a service until recent times was that service was just a way of adding extra value to products. In reality, services cannot be merely added on top of the original goods-dominated total offering. Vargo and Luch (2008) say that if a firm wants to compete effectively through service, the entire organization must be involved. The research by Brax (2005) adds to it that competing through services requires support and change in thinking throughout the whole company. Motivating the customer to the relationship and communication with the customers is also needed throughout the service relationship. It has been also recognized that selling and delivering services really requires a much greater level of engagement with the customer than in the case of goods. (Karandikar and Vollmar 2006).

11.2 Service dominant view

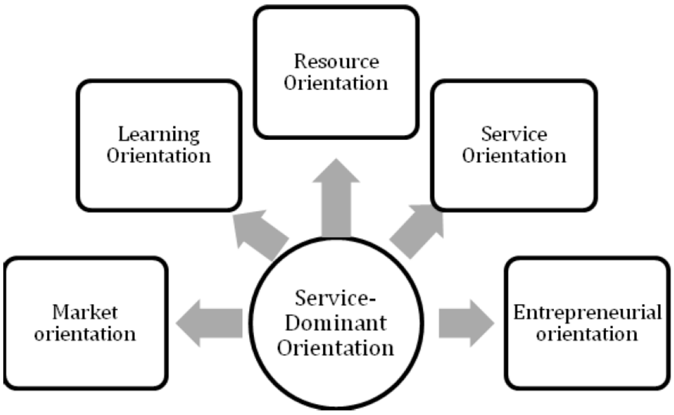
A new view has emerged to fight the shortcomings of the G-D logic. The view has originally a marketing perspective on services, but it however provides a comprehensive view on service management as a whole. Vargo and Luch (2004) call the logic a service-dominant (S-D) logic, Gummesson (2008) calls it Many-to-Many marketing and the Nordic School of economics (Grönroos 2006) calls it the Service logic. There are many similarities in the logics, but the most important one is that all of them agree that the newly developed logic fits well to the context of most businesses producing goods. Other common features with all of the proposed logics are that suppliers and customers are seen as co-creators of service or value. This means that a company creates a value proposition, which is increasingly dependent on input from customers and the customers then create the value actualization either in contact with suppliers or on their own. (Gummesson 2008). The new logic focuses on the process of service when the goods-dominant (G-D) logic focuses on the production of outputs. The G-D logic would state that computers, forklifts, pallets and transportation equipment would be just goods that customer wants. With the new logic they are all appliances for service provision. What customers want is access to the flow of service that these goods facilitate and not necessarily the output or product that firms produce. (Vargo and Luch 2008). The transition from D-G to the new logic in the case of Service dominant logic been illustrated in the table 4.

Goods dominant logic	*Service dominant logic*
Making something	Assisting customers in their own value creation processes
Value as produced	Value as co-created
Customers as isolated entities	Customers in context of their own networks
Customers as targets	Customers as resources
Primacy of efficiency	Efficiency through effectiveness

Table 4. The thinking differences of D-G and S-G logic (Vargo and Luch 2008).

The new logic is built under the idea that individuals and organizations should be brought together into networks and societies, where they can competitively use their best knowledge in collaborative processes with customers, partners, and employees. The logic challenges management at all levels to acquire a perspective that shows the firm how they could be most engaged in the co-creation of value with the customers. (Vargo Luch 2008). Service dominant logic can be applied to almost all businesses, but as Stauss (2005) points out, when moving towards a service dominant logic, goods-based concepts and models may still be useful in situations, where the customer contact is stripped from everything else other than the physical product.

The Service dominant logic has been the topic of many researches in the recent times and it is based on recognized theories, and it is therefore introduced with more detail. The theories that are linked to the Service dominant logic are presented in the figure 22. Deeper analysis regarding the theoretical basis of Service dominant logic is not relevant in this thesis, so for deeper look it is suggested to see the research by Lamberti and Paladino (2013).



Orientation	Description	Main references
Market Orientation	The strategic orientation of a company endorsing the marketing concept	Deshpandé & Webster, 1989; Olson, 1986; Kohli & Jaworski, 1990; Jaworski et al., 1993; Narved & Slater, 1990
Resource Orientation	The strategic orientation of a company that applies the principles of the resource-based view	Paladino, 2007; 2008; Peteraf, 1993; Teece, Pisano, & Shuen, 1997
Service Orientation	The service events, practices, and procedures within a work setting that expect and reward service excellence	Lytle, Hom & Mokwa, 1998; Hogan, Hogan & Busch, 1984; Lytle & Timmerman, 2006; Gonzalez & Garazo, 2006; Heskett, Sasser, & Schlesinger, 1997; Schneider & Bowen, 1995; Schneider et al., 2009
Learning Orientation	The organization-wide activity of creating and using knowledge to enhance competitive advantage	Calantone, Cavusgil & Zhao, 2002; Dixon, 1992; Argyris & Schon, 1978; Sherman, Berkowitz & Souder, 2005; Sinkula, Baker & Noordewier, 1997
Entrepreneurial Orientation	The practices, behaviours and activities encouraging entrepreneurship in the company, where entrepreneurship is the extent to which to which a company innovates, acts proactively, and takes risks	Covin et al., 2006; Lyon, Lumpkin, & Dess, 2000; Lumpkin & Dess, 1996, Hult et al., 2002; Wang, 2008; Baird & Thomas, 1985; Stewart & Roth, 2001; Runyan, Droge & Swinney, 2008

Figure 22. The recognized theories that service dominant logic is based on (Lamberti and Paladino 2013).

In S-D logic, service is defined as:

"The application of specialized competences (knowledge and skills), through deeds, processes, and performances for the benefit of another entity or the entity itself"

The definition represents a shift in thinking between the G-D and the D-G logic. That is, whereas G-D logic sees services as units of output and somewhat inferior to goods, S-D logic sees service as a process of doing something for another party. The focus of value creation therefore is moved from the producer to a collaborative process of co-creation between parties. (Vargo and Luch 2004, 2006a). Service dominant logic is built on ten foundation premises, which create a framework for the service-centred mindset. Principles of the foundation premises encompass three core concepts: "First is the centrality of operant resources, second the interactive nature of value generation and third the participative nature of value generation". (Lamberti and Paladino, 2013). Many of the concepts are neither exclusive to nor invented by S-D logic itself. For example classification of resources involved in value generation and exchange is consistent with Constantin and Lusch's (1994) taxonomy of resources and the Co-creation capabilities theory is grounded in Day's (1994) work on customer linking capabilities. Rather, S-D logic captures the shifting of contemporary thoughts concerning service. The foundation premises are presented in the table 5 below.

	Foundation premises	Explanation
FP1	Service is the fundamental basis of exchange	The application of operant resources (knowledge and skills), "service," as defined in S-D logic, is the basis for all exchange. Service is exchanged for service
FP2	Indirect exchange masks the fundamental basis of exchange	Because service is provided through complex combinations of goods, money, and institutions, the service basis of exchange is not always apparent
FP3	Goods are a distribution mechanism for service provision	Goods (both durable and non-durable) derive their value through use – the service they provide
FP4	Operant resources are the fundamental source of competitive advantage	The comparative ability to cause desired change drives competition
FP5	All economies are service economies	Service is only now becoming more apparent with increased specialization and outsourcing
FP6	The customer is always a co- creator of value	Implies value creation is interactional
FP7	The enterprise cannot deliver value, but only offer value propositions	Enterprises can offer their applied resources for value creation and collaboratively (interactively) create value following acceptance of value propositions, but cannot create and/or deliver value independently
FP8	A service- centered view is inherently customer oriented and relational	Because service is defined in terms of customer-determined benefit and co-created it is inherently customer oriented and relational
FP9	All social and economic actors are resource integrators	Implies the context of value creation is networks of networks
FB10	Value is always uniquely and phenomenologically determined by the beneficiary	Value is idiosyncratic, experiential, contextual, and meaning laden

Table 5. Foundation premises of the Service Dominant logic (Vargo and Luch 2008).

There is of course still a place for goods in the service dominant and in other new views also as goods and other resources are often present in the consumption processes of service. For example in a restaurant, the meal consists of many ingredients as well as by waiters who take the order and serve the meal. In the service dominant view (Vargo and Lusch 2004, 2008) goods are considered as transmitters of service and as a distribution mechanism for service provision. Another view on the role of goods in the service processes comes from the Nordic School (Grönroos 2006), where goods are seen as one type of resource alongside others, such as people, systems, infrastructures and information. The service is seen as the process where these resources function together with each other and interact with the customer as a co-producing resource. Depending on how this process functions and on its outcome, more or less value emerges for the customer (Grönroos 2006).

Goods and services are also sometimes bundled together, and according to Davies (2003b, 2004) research, increasing interest for integrated solutions has recently been emerging. Services are seen more and more as real business possibilities as addressing customer needs through combining services with products has been seen to provide competitive advantage (Davies, 2003b, 2004). Goods and services are both essential parts in an integrated solution offering. In this work, the following definition for integrated solutions, which is provided by Brax et al., is used: An integrated solution offering is "*a bundle of physical products, services and information, seamlessly combined to provide more value than the parts alone."* According to the definition the integrated solution also: *"addresses customer´s needs in relation to a specific function or task in their business system; it is long-term oriented, integrates the provider as part of the customer´s business system, and aims at optimizing the total cost for the customer"*. (Brax and Johnsson 2009).

11.3 **Service processes**

Understanding how services work requires understanding that the services have a process nature. It is important to realize that from the processual nature of services follows that the consumption and production of services are at least partly simultaneous processes. This leads to a situation where customers consume the service while it is produced and are therefore involved in the service production process. Likewise the service provider can at least partly see the consumption process. The production of services is therefore an open system for the consumer and similarly the consumption of services is an open system for the service provider. (Grönroos 2006). The fact that services emerge in open processes where the customers participate as co-producers and hence can be directly influenced by the progress of these processes, is a big difference to the production of physical goods which are produced in closed production processes where the customer only sees the outcomes of the production process. The closed process is the outcome of the non-interactive nature of goods which results to a situation where the firm does not know what the customer is doing with the goods. (Grönroos 2006).

As the customer take part to the production process, the customer has a view inside of the company. According to the many researches (Silvestro et al. 1992, Jaakkola et al. 2009) the processes which are visible to the customer processes are called the front office forming the interface between the company and the customer. The internal processes, which are still invisible to the customer, are called the back office processes. The back office activities are typically treated separately from the front office activities and aimed at increasing efficiency, productivity, and control. The coordination between the front-office and back-office parts of service organizations is commonly handled with a downstream customer philosophy, which casts each operating unit as a service supplier to the next downstream operation unit, thereby establishing internal supplier-customer relationships. (Zomerdijk and Voss 2010).

According to Silvestro et al. (1992), the orientation of the company's processes reveals the archetype of the company's service offerings. The companies emphasizing the front office processes most often offer professional services, with relatively few transactions, highly customized offerings, relatively long contact time and a process orientation. The companies which emphasize the back office processes usually offer highly standardized services with limited contact time and just a little customization to a large lot of customers, and therefore fall to the mass services archetype. If the process orientation is balanced between the front and the back office, the company belongs to the last archetype: service shops, which fall between the professional services and mass services.

As the services are processes there must be a definition of the process the firms offer. According to Vargo and Luch (2008) most enterprises are organized to manage compartmentalized tasks and activities. Therefore when a problem occurs the focus is on the local concern and not on fixing the systemic problem. A more preferable way of dealing with service processes is the definition of the service process by describing the service implementation phases accurately. (Vargo and Luch 2008). Describing the service process assists in finding out who will be involved in providing of the service, at what point and for how long period of time. Once the service process is known, the resources that are needed for the offering of the service can be determined, activities can be designed and more efficient delivery schedule and more precise evaluation of the costs affiliated with service can be executed. (Jaakkola et al. 2009).

The service processes can be described by simple action/process charts, which include the activities belonging to the service process and the persons involved in the co-production of the service. Service description focuses on processes of how the firm interacts with customers. A typical service process chart breaks out four components; customer actions, front office contact employee actions, back office contact employee actions, and support processes. (Zeithaml et al. 2006). The most important role of the charts is the describing of the service process, so that all of the necessary steps and resources spent on the process are mapped. (Jaakkola et al. 2009). This mapping of activities that are involved in the service process can be accomplished with a number of techniques, often referred to as process mapping, service blueprinting or activity mapping. The mapping is used for forming the basis for the co-operation between the different parties and for the designing and scheduling of the service. (George and Gibson 1991). All of the mapping techniques are based on industrial engineering flowcharting. With these maps the focus is on the mapping of processes and service flows, rather than just on tasks, activities or functions, which supports the early ideas for example of Shostack et al. (1987) who suggest that services "must be viewed as interdependent, interactive systems, not as disconnected pieces and parts." Luch et al. (2007) share the same ideology saying "it is recognized that customer service problems are not the fault of the customer service department (the department charged with fixing the problem) but that the problem is deeply rooted in a more general process failure." The research by Luch et al. (2007) suggest that firms should go a step further by mapping the customer's role in value co-creation, which would support the central aspects of the service dominant logic.

11.4 Service design

Maintaining a commitment to continuous improvement of services is one fundamental aspect of service management. Therefore adding new tools like the tool under research to the work of eService could change the basic routines of eService experts, which might result in the development of the service processes or even allow emerging of new service products. To further explore the possibilities, the processes of service development are presented.

Research has shown that the design of new services is the most important factor when a company is trying to achieve competitive advantage through services. Service innovation and design give birth to new offerings yielding opportunities to increase revenue, expand market share, and enhance profits. Still the idea that new services just arise without much effort was common until it was recognized that developing services requires a well-defined development process. (Menor et al. 2002). In designing a new service or redesigning an existing service, managers and designers must make decisions about each component of the service. For even a relatively simple service, numerous decisions are made in taking a new or redesigned service from the idea stage through the design phases to a deliverable service. The large number and wide variety of decisions required to design and deliver a service and the fact that the decisions are made at several levels in the organization makes the process even more challenging. (Goldstein et al. 2002). The commonly used term for the development of new services is the new service development (NSD), which is defined as "the overall process of developing new service offerings" (Johnson et al. 2000). Johnson et al. (2000) have captured the basic four general stages of the NSD process as: design, analysis, development, and full launch.

1. Design stage involves going through of the new ideas to find those with the greatest profit potential and setting new service strategy and objectives that create the general boundaries for idea generation. (Johnson et al. 2000). According to Melton et al (2011), customers and the front office employees should be included in the design stage to generate more innovative ideas.

2. Analysis stage consists of assessing the potential profitability of the project and obtaining of the company authorization to proceed. (Johnson et al. 2000).

3. In the development stage, the firm develops and tests the core service, delivery system, and associated marketing program and trains the needed personnel. (Johnson et al. 2000). Customers should be included in this step according to Melton et al. (2011), to capture the reactions to service prototypes enabling developers to refine the product in a way that achieves unique value by the target market.

4. Full-scale launch is the final stage of the NSD process launching the new service to the entire target market. The final stage also includes the review of the launch to evaluate performance. (Johnson et al. 2000). Melton et al. (2010) accentuate, that firms should involve front office employees in this stage by thoroughly motivating and training them to effectively promote and deliver the new service.

Service was once related only to face-to-face interactions between two people, one offering the service and the other receiving it. Today service domains and interactions are vastly more complex and the designing of services is a difficult task as service designers must combine and integrate the value created in different service design contexts. (Spohrer et al. 2007). According to Glutscho (2010) seven contexts in which services are presented can be recognized from the service design. The contexts are: person to person encounters; technology enabled self-service, computational services, multi-channel, multi-device, and location-based and context-aware services. The research by Glutscho (2010) highlights that although it is useful to consider multiple points of view when designing new services, it is essential to select one as primary as the choice shapes the priority of design requirements, constraints, and information sources. The choice also has impact on design patterns, it identifies what processes belong to the front office and which to the back office and it has influence on the creation and capturing of value. For example in a normal restaurant defined from the customer's point, the dining room would be the front office and the kitchen would be the back office. If the same restaurant would be transferred into cooking school the customers eating the food in the dining room would belong to the back office providing feedback to the cooks and the kitchen would be the front office. (Glutscho 2010).

Besides the NSD processes and the point of view- selection, it is also important to understand the concepts of the services when designing and developing services. According to Goldstein et al. (2002) the service concept plays a key role in service design and development as without a clear and shared understanding of the nature of the service to be provided, or in other words of the service concept, it is impossible to design a successful service. The service concept therefore serves as a driver of the many decisions made during the design of service delivery systems and service encounters. Johnson et al. (2000) define the service concept as “a detailed description of the customer needs to be satisfied, how they are to be satisfied, what is to be done for the customer, and how this is to be achieved.” There is also a more detailed definition of the service concept by Clark et al. (2000), and Johnston and Clark (2001), which divides the service concept into four parts: The service operation, which is the way in which the service is delivered; the service experience developing from the customer’s direct experience of the service; the service outcome, which consists of the benefits and results of the service for the customer and finally the value of the service which is defined as “the benefits the customer perceives as inherent in the service weighed against the cost of the service.” The service concept therefore helps the service designers to understand that customers and service providers view services also in other ways than as a sum of components, like in the blueprinting method, also since the services can also be seen as a singular outcome that is sought from the service process. (Goldstein et al. 2002).

The service concept is a core element of the design process and it provides the design process with information of the nature of the service. The service concept is the customer’s and service provider’s expectation of what a service should be and what customer needs it should fulfil. (Clark et al. 2000). According to the research by Goldstein et al. (2002) the service concept brings a definition to the service design concerning how the service should be delivered and what belongs to the service. The service concept also ensures the integration between different aspects and can also help with the balancing between customer needs and the organization’s strategic intent. According to Goldstein and al. (2002) “one reason for poorly perceived service is the mismatch between what the organization intends to provide (its strategic intent) and what its customers may require or expect (customer needs)”. The figure 23 further explains the basic structure of the service concept.

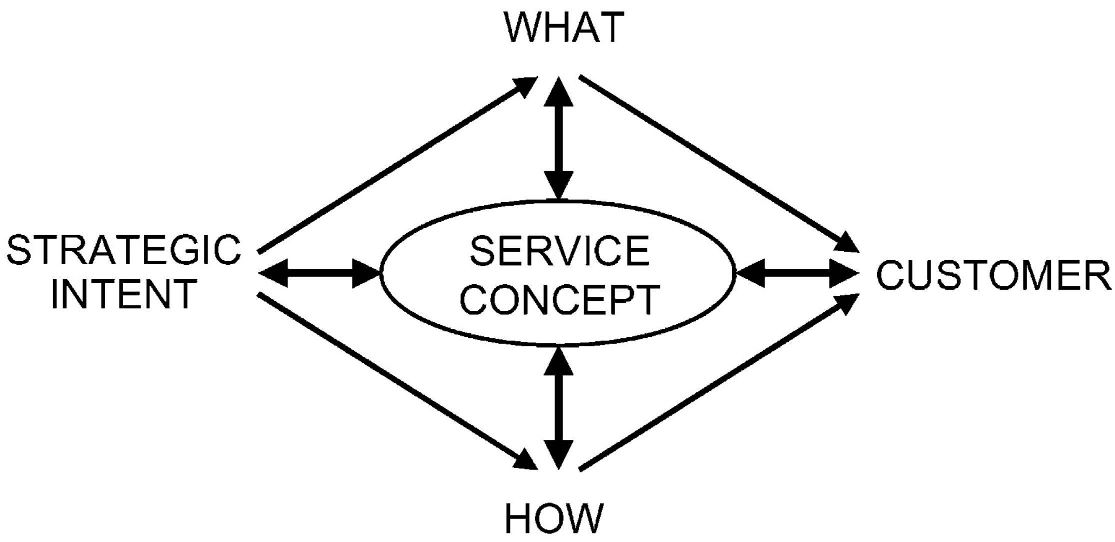


Figure 23. the basic structure of the service concept (Goldstein et al. 2002).

The service concept provides a framework for evaluating services on an on-going basis as services change and improve. Understanding what customers want and expect provides the basis for designing service processes that meet those needs. (Goldstein et al. 2002). It is also important to combine customer and front office employee involvement in the NSD process since this allows the production of market-tested services that satisfy clearly identified customer needs. (Melton et al. 2011). Using the service concept to drive the design decisions provides consistency to their service design. (Goldstein et al. 2002).

11.5 Service quality

The service quality has been identified to have five key dimensions. (Parasuraman et al. 1988). The five dimensions of service quality are tangibles, reliability, responsiveness, assurance and empathy. The tangible dimension is about creating first hand impressions, the reliability dimension refers to how the company is completing their promised service, responsiveness is the willingness to help customer and provide prompt service and assurance is the knowledge and accuracy of employees and their ability to convey trust and confidence. The empathy dimension refers to how the company cares and gives individualized attention to their customers. The empathy dimension is a higher level combination of reliability responsiveness and assurance. (Parasuraman et al. 1988).

These measures have been applied in and adapted to many industry settings. It is however difficult for customers to express precisely what they expect from a service, since there is no agreed objective standard about the service to be delivered. Customers do not evaluate service quality solely in terms of the outcome of the interaction; they also consider the process of service delivery. Service quality is therefore a multidimensional construct encompassing all the aspects of service delivery, making the process difficult to assess and communicate. (Oliva and Sterman 2001). Therefore the only criteria available to evaluate service quality are subjective comparisons of customers' expectations to their perception of the actual service delivered. (Zeithaml et al. 1990). In this work, the service quality is therefore defined as the difference between the customer expectations of service and the perceived service.

According to Zeithaml et al. (1990) Customers have a tendency to compare the service they receive with the service they thought they would receive. If the received service experience does not match the expectations, there arises a gap, meaning that customers can evaluate a firm's service quality by comparing their perceptions with their expectations. This observation is the cornerstone of the most often used quality measurement tool: the SERVQUAL model. SERVQUAL, also called the Gaps model of service quality, provides a strategic foundation for organizations that wish to deliver service excellence to their customers. The SERVQUAL was first introduced in 1985. (Parasuraman et al. 1985, Zeithaml et al. 1990). For over twenty-five years it has been used across industries worldwide helping companies to formulate strategies which would deliver quality service integrating customer focus across firm functions and providing a strong foundation for the strategy of the service business. (Bitner et al. 2010). The SERVQUAL model of service quality in the figure 24 illustrates the full model of service quality, adopted from the researches by Parasuraman et al. (1985), Zeithaml et al. (1990) and Bitner et al. (2010).

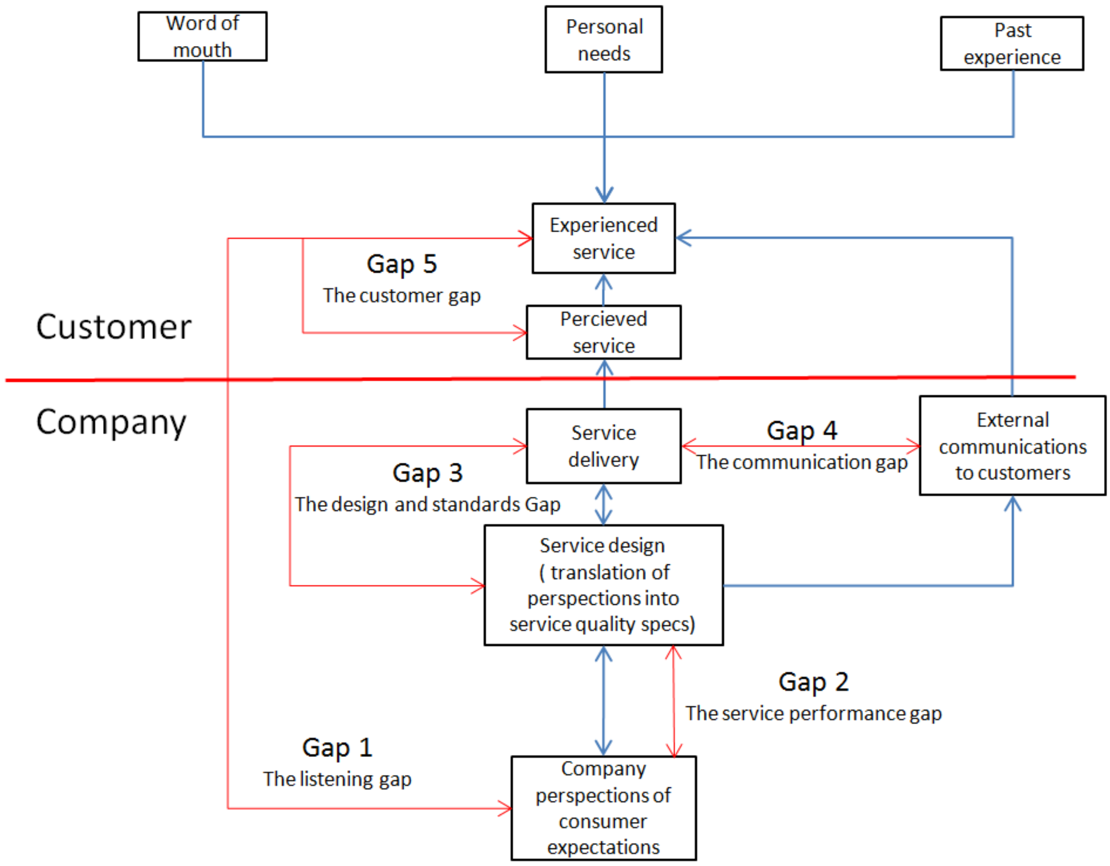


Figure 24. The Gaps model of service quality (Parasuraman et al. 1985, Zeithaml et al. 1990, Bitner et al. 2010).

The centrepiece of the model is the Gap 5; the Customer Gap, which is the gap between customer expectations and perceptions of the service as it is actually delivered. The final goal of the model is to close this gap by meeting or exceeding customer expectations. The other four gaps in the model are known as the provider gaps each representing a potential cause behind a company's failures in reaching the expected quality.

The cause first gap (Gap 1) results from not listening to customers and therefore the company lacks accurate understanding of exactly what the expectations of the customer are. They may not interact directly with customers, they may be unwilling to ask about expectations, or they may be unprepared to address them. It is important to clarify the customer expectations accurately before any new services are developed (Zeithaml et al. 2009) as the failure of the service which follows the omission of this phase, is well studied and documented. (Tax et al. 1998). The figure 25 expresses the key strategies of closing the listening gap.

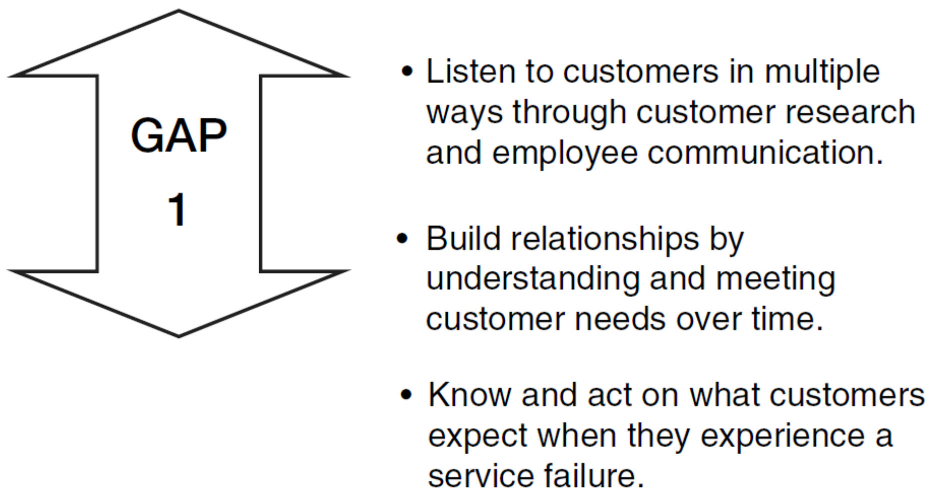


Figure 25. The key strategies for closing the listening gap (Bitner et al. 2010).

According to the developers of the SERVQUAL model (Parasuraman et al. 1985, Zeithaml et al. 1990, Bitner et al. 2010) closing the Gap 1 alone is not sufficient since even when a company has a thorough and ongoing understanding of its customers' expectations; it is still very possible, in fact quite easy, to fail to deliver quality service. The second gap (Gap 2), the design and standards gap, is the next gap to be closed in preventing a service failure. The second gap results from not managing to translate expectations into actual service designs and failing to develop standards to measure service operations against customer expectations. The closing of this gap is not easy, as the development of services is a complicated process, as was explained in the latter chapters. The figure 26 summarizes the key strategies for closing the gap 2.

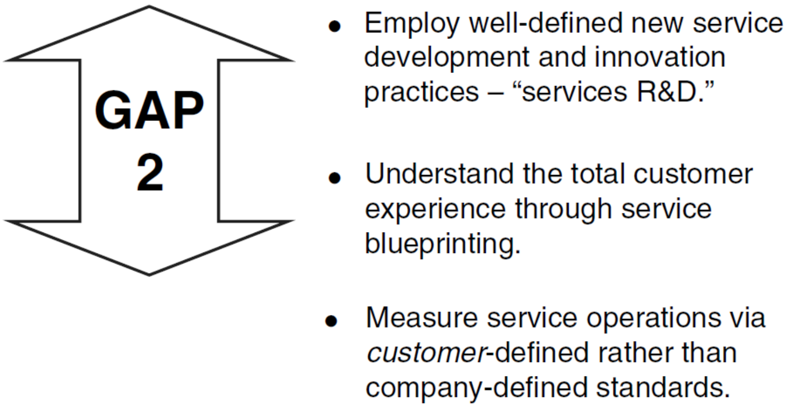


Figure 26. The key strategies in closing the gap 2 (Bitner et al. 2010).

The company might have closed both the Listening Gap (Gap 1) and the Service Design and Standards Gap (Gap 2) but it still might fall short of providing service that meets customers' expectations. (Bitner et al. 2010). Gap 3, the service performance gap, results from not delivering the service in the way the service was designed, resulting poorly performing services. The gap 3 must be closed to make sure there are no inconsistencies between the customer-driven service design, the standards and the actual service delivery (Zeithaml et al. 2009). Even when there are guidelines for providing well performing service and treating customers correctly, high-quality service performance is not a certainty. (Bitner et al. 2010). The figure 27 summarizes the key strategies for closing the gap 3.

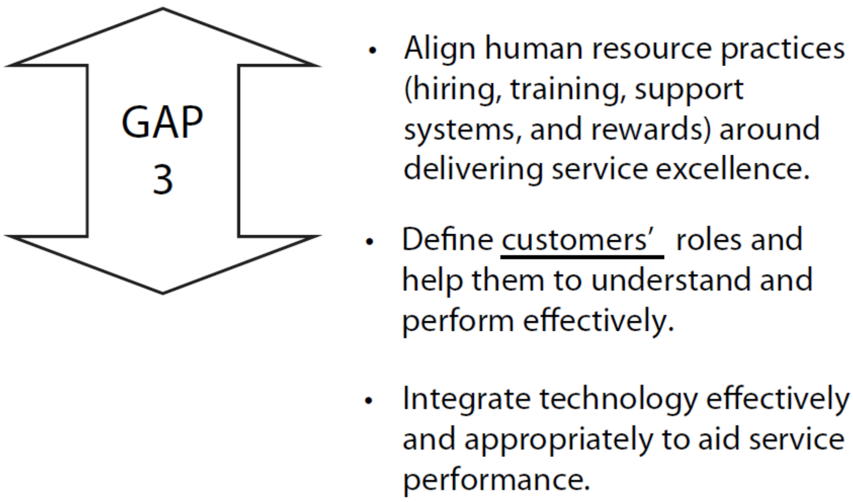
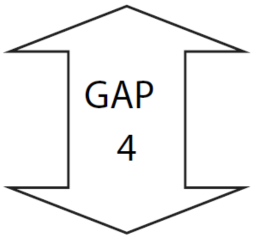


Figure 27. The key strategies for closing the gap 3 (Bitner et al. 2010).

Even if the company manages to close all the gaps mentioned before, there can still be a failure to meet customer expectations if communications about the service do not match with what is delivered. Gap 4, the communication gap, results from the difference between service delivery and what is communicated externally to customers through advertising, pricing, and other forms of tangible communications. (Bitner et al. 2010). Figure 28 captures several key strategies for closing the Gap 4.



- Employ integrated services marketing communication strategies around everything and everyone that sends a message or signal to the customer.
- Manage customer expectations effectively throughout the experience.
- Develop mechanisms for internal communication to avoid over-promising and ensure successful delivery.

Figure 28. The key strategies for closing the Gap 4 (Bitner et al. 2010).

The SERVQUAL has been the most popular quality measuring tool for over 25 years and it has been used across industries worldwide. (Bitner et al. 2010). The popularity of the SERVQUAL model can be explained by the three main contributions of the model. Firstly is has a business perspective, which makes it easier to implement in practise. The SERVQUAL also incorporates theories, ideas, and frameworks from multiple academic disciplines making it a believable tool. Lastly the model has a keen focus on the customer, making the model well suited in the modern business. (Bitner et al. 2010).

Even though the SERVQUAL model has a strong theoretical foundation, criticism against the model has emerged also. In the research by Buttle (1996) the SERVQUAL model is critiqued and three key problems are presented. Firstly the critique argues that the perception and expectation are very subjective and therefore they are not good measures and therefore the measures in the model are not necessarily the right things to be measuring. The research also states that that there isn’t necessarily a direct relationship between service and quality. The SERVQUAL has been criticised in the research by Asubonteng et al. (1996) also, which stated that “there is still more work to be done to find a suitable measure for service quality” although the research concluded that: "Until a better but equally simple model emerges, SERVQUAL will predominate as a service quality measure"

12 RESULTS FROM THE LITERATURE REVIEW

One of the main goals was to identify the methods used for automatic analysis of BMS to highlighting identified best practices. Adding tools which use automatic analysis to the work of eService seems to have great potential in making the work of eService unit more efficient. The amount of usefulness depends on the methods that are used in the tools, as different methods have different strengths and weaknesses and they are suitable in different situations. Tools using simples qualitative methods can be easy to develop and apply but the results are not as reliable as with more complex qualitative methods, or the quantitative methods. For example fewer types of faults can be detected with qualitative models and the levels of the faults that can be detected become coarsened. The models implemented with quantitative methods provide the most accurate diagnostics, but they can be overkill for most situations.

Qualitative methods, like heuristic rule based systems, provide shortcuts offering the most appropriate way to meet the needs of automatic analysis and diagnostics in monitoring of noncritical processes, where quantitative approaches would take too much time and be too costly. Qualitative methods are a good choice in situations where relationships are hard to form and parameters are hard to set or identify. The qualitative methods usually use rules, which have different variety of intelligence implemented in them, to draw conclusions. The qualitative methods also include methods like fuzzy logic, which provide means to reason even under uncertain circumstances and means to perform diagnostic tasks without precise knowledge of the system and without exact numerical values for inputs and parameters. On the down side, fuzzy logic provides imprecise diagnostics making fuzzy logic useless in processes that are vital to the system or in cases where it is important to avoid false alarms.

The diagnostics provided by the simpler qualitative methods can be explained more easily than the diagnostics provided by quantitative methods, as the cause-effect relationships can easily be read from the rules. Applying heuristic first principles based rules for whole building would still most likely offer too simplistic analytics and unreliable performance. Common problem with qualitative and basically all rule based systems, is the difficulty to make complete sets of rules, which would cover all possible behaviours of the system. The difficulty increases when the systems grow complex and with the swelling rule collection, the simplicity and the transparency of the reasoning behind the diagnostics is lost. Expert systems are the most complex of the qualitative methods. Expert systems are based on parameter comparison and expert rules. Expert rules can be thought of as a thinking process of an experienced engineer. The applicability of models implemented with qualitative methods therefore depends largely on the expertise and knowledge of the developers. Therefore expert systems are dependent on capable teams using and developing them. The literature review has revealed that it is unlikely that even expert systems would achieve the high levels of reliability that would be required from the methods used for automatic analysis of BMS.

Although qualitative methods are preferred over the quantitative methods in many scenarios, the quantitative methods still have several strengths over the qualitative methods. Detailed physical models can model both normal and incorrect operation and they are the only method which can model the transients in a dynamic system. The quantitative methods however can be complex and computationally intensive and the effort required to develop physical models can be significant. Quantitative physical models usually require a vast amount of variables to describe the system, some for which measurements or values may not be readily available. Therefore quantitative models are often an impractical choice for modelling. The high complexity and dimensionality of the process and the lack of good system data often limit the usefulness, making the methods an unlike choice to emerge as the method of choice in the near future. Generally both qualitative and quantitative methods require prior knowledge of the building and circumstances for the model development and therefore the models are often building specific and therefore hard to apply to other buildings. Quantitative methods are however based on physics, so there is a possibility to use equipment specific models with different buildings, although the creation of the models requires much effort.

From the data based methods, the statistical parametric methods are often considered to be the most potential statistical methods for automatic analysis because of their ability to tune the model with empirical data from the building. These methods are well suited to problems for which theoretical models are poorly developed or inadequate to explain observed performance. Black-box models are easy to develop and do not require any understanding of the physics governing in the system, unlike grey-box models which often require more thorough understanding of the system. Grey box models therefore are suited in the situations where there is some knowledge available concerning the physics in the system and the black boxes in the situations where there is no prior knowledge of the system available. Black box methods, as well as other data based methods, require large amounts of training data including data from normal and from the faulty operation. This makes the data based methods only suitable in places where training data are plentiful or inexpensive to create or collect. Generally the less knowledge there is concerning the system, the less the method can used for extrapolate beyond the range of the training data. According to the literature review the grey box models have great potential in fault detection and diagnostics applications when compared to black box models. Grey box models usually give more robust parameter estimations than black boxes, providing a better quality for the predictions extracted from the grey box model. Grey box models are therefore one of the most potential methods for automatic analysis of BMS.

From the new methods bond graphs have an interesting approach on fault diagnostics, as the development of a bond graph model begins from a simplification and then grows more complex. Bond graphs provide an effective modelling process, which is unified to all situations. PCA method in the other hand requires only fault free training data for the model development, which removes the problem of introducing artificial or actual faults to the system only to get faulty data. The support vector machines on the other hand require only small amounts of training data still showing higher diagnosis accuracy than for example black boxes. There are however reasons why these methods have not yet become major diagnostic methods. There is no way to model thermodynamic processes with bond graphs. At the same time, the PCA does not readily work well with the nonlinear processes suggesting that there is a clear place for improvement to make these methods more usable. The support vector machines do not have as great problems in the usability than the PCA or the bond graph method, although the sensitivity to faults is not as good for example with PCA methods.

The methods used for automatic analysis have different uses and the methods can be used to supplement each other's weaknesses. Ultimately the tools that utilize these methods will show what methods are to become the best practises.

There are several diagnostic tools capable of automatic detection and diagnosis of energy and other performance problems found from buildings. Many of the tools can prioritize and summarize relevant performance problems, display plots for visualization, and perform automated diagnostic procedures. The installation process for each of the tools reviewed was similar and consisted basically of the four steps:

1. Collecting needed data from the site.
2. Installing the necessary hardware, sensors and any external communication equipment.
3. Data processing and the creation of a baseline of energy use.
4. The setup of diagnostics reporting.

The effort needed for installation and configuration, however varies significantly between the tools, mainly depending on the complexity of the tool. ABCAT is built to predict the energy consumption of a building under changing weather conditions. The simulated energy consumption is then compared to the measured energy consumption to highlight the faults which have the biggest impact on the energy consumption. ABCAT is fast and cheap to implement and the approach on automatic analysis is quite simple. PACRAT at the same time has a much more complex approach on automatic analysis than ABCAT. PACRAT uses black box and a multiple variable bin method with expert rules which are based on the first principles. PACRAT can detect over fifty different types of problems and the implementation process of the tool is heavy and costly. WBD´s diagnostic capabilities lie in the middle of the latter tools. WBD offers diagnostics, unlike ABCAT, and WBD focuses on a few specific system diagnostics, unlike PACRAT for which the target is to find all of the problems in the system. Infometrics has the most unique approach on automatic analysis from the tools reviewed. There is practically no usable information available on how the diagnostics are generated in Infometrics, as the customer sees only the reports from the program.

Infometrics is the only toolset that is purely service based. There is no software offered to the customer and instead a Cimetrics mechanical engineer is pre-analysing the reports generated by the system. The customer then receives a clear prioritized list of faults, causes and repairs for them. This approach increases the accuracy of reports and does not rely on the customers own staff´s motivation to check the reports. On the other hand the on-going expense can become too costly in a long run. The rest of the tools followed software as a service (SaaS) business model, but with big alterations on how the approach can be done. Sites which have sufficient staff to read fault reports and troubleshoot faults, the SaaS approach is a suitable business model. In general, the reliance on the staff´s actions in cases where the staff is already busy, the SaaS approach is not ideal.

Since reports are the primary delivery method of information by the tool to the end user, reporting is an invaluable aspect of tools offering automatic analytics. All of the tools offer some levels of reporting, but the reporting of Infometrics seems superior to the other tools as the reports are highly accurate. The approach on WBD does not count solely on the skill or dedication of operators in interpretation of diagnostic graphs. Instead WBD has been designed for operators with a little time and therefore WBD communicates the diagnostic results with colour maps, which allows users to get a basic understanding of the state of the system with one glance. The reports are focused mainly on the most significant problems and the reports are clear and fast to interpret. In the case of PACRAT, data can be viewed in user-defined graphs and links that connect a specific anomaly to the relevant data that generated that anomaly. PACRAT is therefore clearly built to be a tool for professionals who have the time and skill to interpret vast amounts of data. PACRAT reports energy consumption information better than the rest of the tools by maintaining two energy consumption baselines. The automated diagnostic capabilities of ABCAT also rely on the experience and knowledge of the user.

From the literature review it can be concluded that to be able to implement programs like ABCAT of PACRAT successfully, there must be a person in charge of the tool ensuring that detected faults and problems are addressed and fixes are implemented. The research by Ulickey et al. (2010) comes to a resembling conclusion claiming that there should be “a champion” on the site ensuring that faults are addressed in timely fashion. A champion is often needed because deploying a tool offering automatic analysis could tax the operations and maintenance budget at a facility as resources are likely to be needed to address identified faults. According to the literature review, it is clear that the diagnostic technologies alone will not result in system efficiency improvements. Improvements can only be realized in the buildings where identified problems are corrected. Therefore not alone the diagnostic capabilities matter in the tool, but also the business model and the reporting capabilities have great impact.

13 RESULTS FROM THE PILOT STUDY

The results from the pilot study are presented in this chapter. The first phase of the pilot was completed in August and the second phase one month later in September. The tool was under observation for 19 weeks and the tool still continues to run after this thesis has been completed. During the 19 weeks the tool generated hundreds of reports. During the first week of the first phase, the piloted tool generated 20 reports from 12 different sources (or in other words there 12 unique faults). The amount of faults remained at the same level until the heating and cooling equipment were connected to the tool, which almost doubled the amount of reports. The exact numbers of faults are drawn in the figure 29 below. The faults in the figure 29 are categorised by type of the fault. The faults which have high comfort priority are categorised as comfort faults, the faults which have impact on the energy consumption are categorised as energy faults and the faults which have high maintenance priority are categorised as maintenance faults. The figure 29 also shows the weekly unique faults.

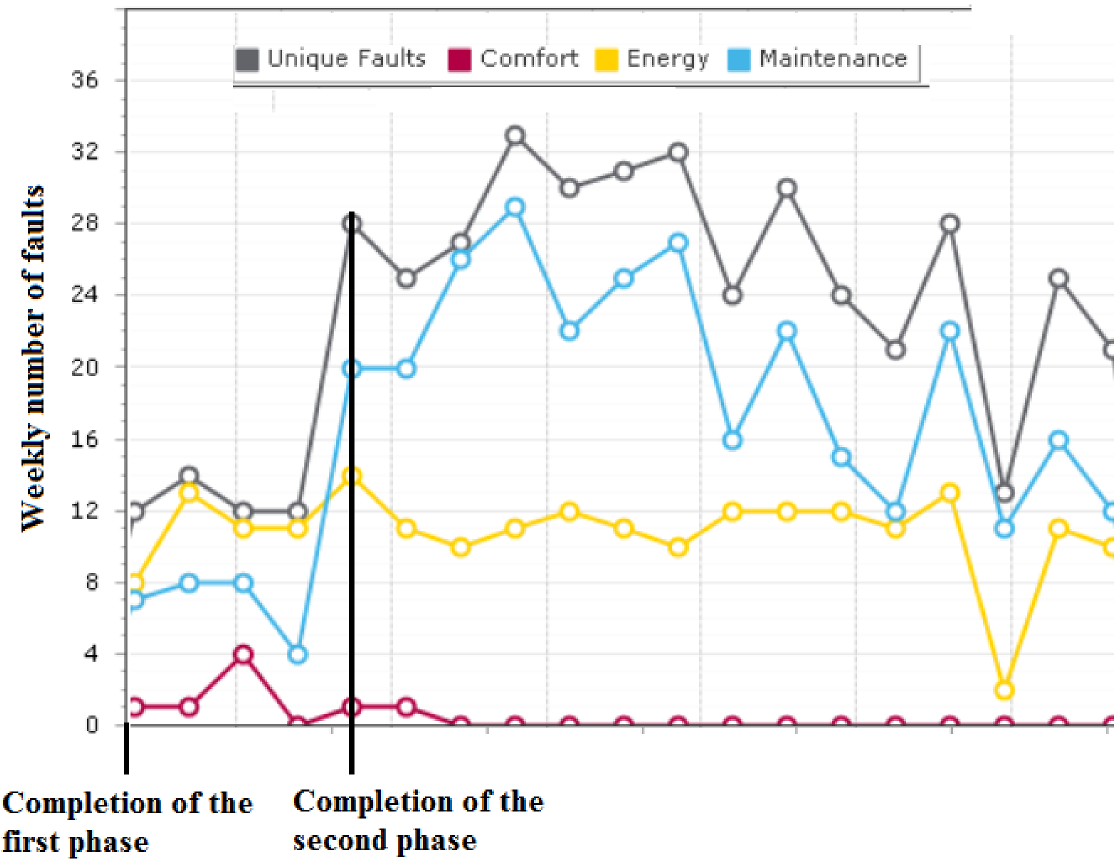


Figure 29. The amounts and the types of faults generated weekly by the piloted tool.

The amount of faults did not dramatically drop during the test period. The trend was however declining as some repairs and tweaks were introduced to the system by the eService experts. The generation of faults felt responsive to the repairs throughout the pilot, as the reports from a specific fault instantly vanished when repairs were introduced to the problem. The reports were mainly of low priority with only a few exceptional reports having the highest priority. The average priority of faults was 3.5 from a scale from 0 to 10.

As the eService expert in charge of the piloted building was under a huge workload from getting to know the building and dealing with the biggest problems, the low priority and low saving potential on the majority of faults led to a positive problem of not having significant faults and therefore not having much real faults to report. The problems which kept the eService expert in charge of the building busy were mostly not detectable by the tool. The problems could not be detected because of missing measurements which would have been required for the tool to notice the faults. Also faults which were connected to the design of the building´s HVAC system could not be detected by the tool, as repairing these problems would have required a deeper understanding concerning the operation of the building. The same challenges were recognised in the literature review, as the variable and nonlinear circumstances in which the HVAC equipment in the building operates and missing measurements accompanied with faulty sensors were seen as the biggest challenges of automatic analysis of BMS.

During almost the whole pilot we thought that there were only a few problems detected by the tool having money saving potential in them. Then just a few weeks before planned completion of this thesis, there were some repairs introduced to the heating network settings of the piloted tool, which resulted in generation of a significant amount of new savings possibilities. As can be seen from the figure 30 presenting the avoidable costs before the repairs; all of the faults which had money saving potential were generated during the first weeks. In reality there were however more savings possibilities existing, which can be seen from an updated version of avoidable costs now from the 22 weeks the tool was under observation from the figure 31.

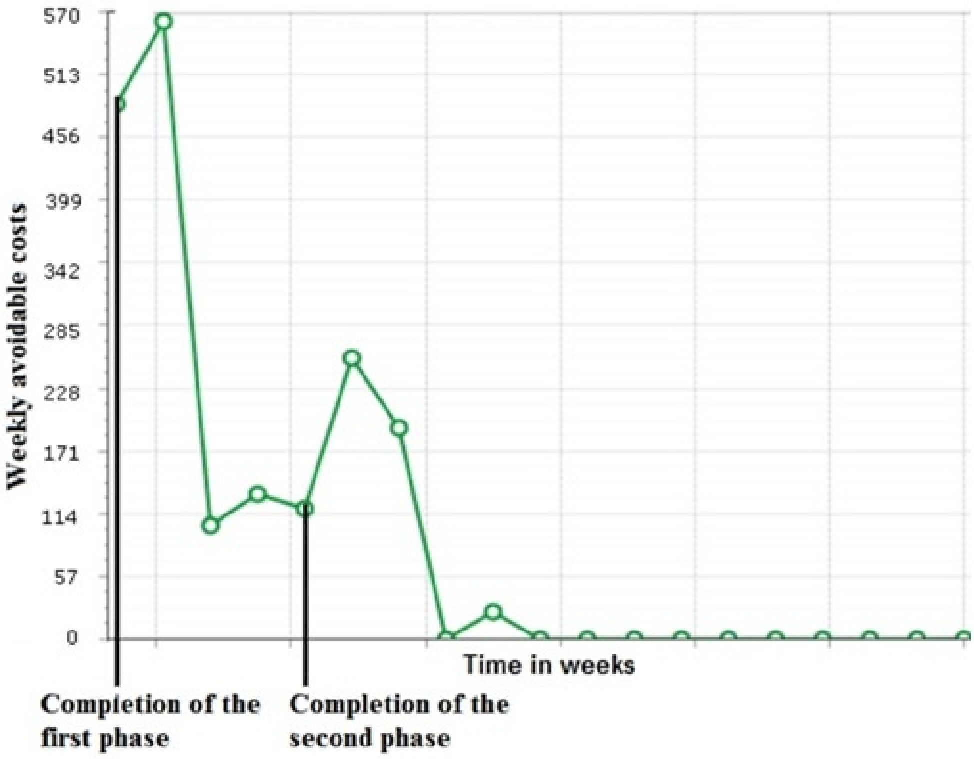


Figure 30. Weekly avoidable costs during the 19 week period.

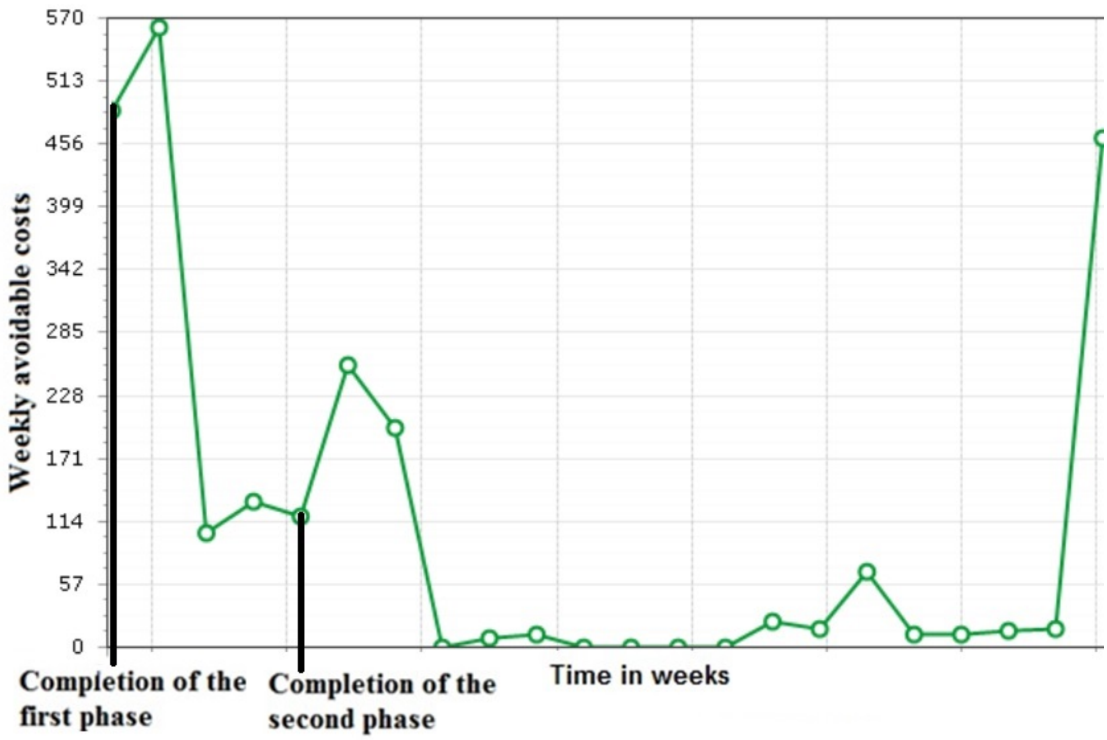


Figure 31. Weekly avoidable costs during the extended 22 week period.

Most of the repairs leading to decreasing of avoidable costs were introduced during regular BMS inspections, without the needing to see the reports from the tool. Only two problems noticed by the piloted tool resulted in introduction of corrections to the system. The first problem, which probably was governing in the system long before the tool was introduced to the system, was linked to a problem in the heat recovery system. The heat recovery system was turning on and off randomly, resulting to the generation of the two biggest peaks in the figure 30. The random behaviour of the heat recovery system resulted in the system entering cooling mode even though the heat recovery exhaust air temperature was higher than the heat recovery inlet air temperature. In other words, the cooling would have been unnecessary during the period, as the outlet air from the air handlers was cooler than the inlet air, so that the inlet air could have been used instead of the cool air produced by the cooling system. Until the fix was implemented to the heat recovery system, the cooling system was unnecessarily on for 55 hours resulting in over a 1000 € worth of possible savings. If the tool had not noticed the fault, the odd behaviour of the heat recovery system could have been continued for a long time, since the problem was only detectable for some hours a day.

Besides the problem with the heat recovery system there was a problem with a convector network heating loop, which had been heating beyond its supply setpoint (sometimes significantly beyond its setpoint) mostly because of a faulty outside air sensor. Nearly all of the avoidable costs that are not present in the figure 30 but are showing in the figure 31, are generated due to the heating loop problem. The normal inspections to the BMS system did not reveal the fault and the fault was only noticed when the temperature in Finland became cold enough to create complaints from the tenants complaining too cold office temperature in the week 22 of the pilot. When the settings in the piloted tool were corrected during the same week, it was revealed that the fault had actually been there 15 weeks unnoticed. If the piloted tool had functioned properly the whole time, the problem with the non-compliance with the setpoints would have been noticed 15 weeks ago and no complaints would have been generated. If the cold weather had not given birth to tenant complaints, the problem would have been left unnoticed until someone would have randomly opened the right trend readings as there was no alarm set to notify the eService experts of this particular situation. The unfortunate incident with setting up of the piloted tool therefore showed how useful the tool really could be as a tool of eService.

Results from the pilot are gathered to the table 6.

A test building 16 air handlers 2 Heating networks 2 Coolers	8/2013- 1/2014	The piloted tool successfully identified a major problem in the heat recovery system and a number of small priority problems from the whole system Problems with many types of equipment were identified The costs from the problem with the heat recovery system were over 1000 € in a little over two weeks in August when there is little heating or cooling actually needed. If the problem would have been left unnoticed for two months, the amount of wasted energy would have been several thousand Euros The problem with the heating network resulted in avoidable costs being over 700 €. If the piloted tool was set up right and the problem would have been repaired early on, the over 700 € of avoidable costs would have been saved

Table 6. Results from the test building.

14 POTENTIAL OF THE PILOTED TOOL IN THE WORK OF ESERVICE

Advantages of introducing the piloted tool to the work of eService are presented in this chapter. First the most useful features of the piloted tool are presented and then the usefulness of these features in the work tasks of eService is evaluated. The piloted tool monitors real time data and historical trend data from building management system and therefore offers continuous monitoring. The data collected by the tool is automatically analysed every day to identify malfunctioning equipment. The piloted tool diagnoses problems, identifies savings opportunities and suggests repairs and adjustments. The information is presented in an online interface with detailed findings which include specific and prioritized cost and energy savings opportunities. The most useful features of the piloted tool are collected in the table 7 below:

Feature	Short description
Continuous monitoring	The ability to continuously monitor the behaviour of the system, allowing noticing of the persisting faults that occur only randomly
Identifying and pinpointing problems, causes and repairs to the problems	The ability to identify when a problem has occurred, pinpointing the type of the problem and its location. Also the ability to find the possible causes and the ability suggest actions regarding repairing of the problems
Reporting of both problems and diagnostics to the user	Reports are the primary delivery method of information by the tool to the end user so the ability to report the findings accurately is important
The option to view graph data	Ability to view data in graphs

Table 7. The most useful features of the piloted tool.

14.1 Effects on the work of eService

One of the main challenges in the work of eService is the capability to handle the huge amount of equipment that is found from the buildings under supervision. If there are no alarms set, or if the alarms are not be under eService responsibility, it is possible that the alarms are just left unchecked by the janitor. The problem might therefore be left unnoticed for a long time. The monthly regular inspections ensure that the problems will be noticed at some point, but most often these problems are revealed by the customers' complaints. The piloted tool would notice these kinds of problems sooner and lessen the customer complaints.

The basic eService tasks includes energy efficient use of the BMS, which is carried out by checking and adjusting the pre-set values and control loops, the operating schedules and control settings from the building management system. Continuous monitoring notices persisting faults that occur randomly, like for example the fault in the heat recovery system which was found from the piloted building. Continuous monitoring allows the BMS to be initially commissioned maintaining comfort. The tool generates suggestions for continuous re-tuning of the BMS and suggests improvements to operating schedules. The tool also informs the user if the control settings are not optimal. The piloted tool´s capabilities to offer continuous monitoring seem therefore extremely useful for the basic tasks of eService.

The piloted tool would be useful in the tasks linked to the EnergyEdge (EE) programs also. EnergyEdge projects include an energy audit and facility analysis to discover energy saving opportunities. The savings in the EE projects are accumulated by implementing fixes and improvements to the HVAC system in the building and by setting the BMS system to work energy efficiently. The piloted tool´s many features which were seen useful in the basic work of eService are mutually useful in the EE projects. The list of faults prioritized by energy use would serve as a useful starting point for the eService expert first starting to look for energy saving measures. The tool would lessen the risks of not finding enough savings by finding problems that are hard to notice without for example continuous monitoring. The data collected by the tool is automatically analysed every day to identify malfunctioning equipment, to diagnose problems and to identify savings opportunities. The tool then suggests repairs to the problems or adjustments to control settings, making the tool extremely useful in the EE projects also.

As the piloted tool offers continuous monitoring, it instantly notices impaired performance and therefore helps the eService to detect emerged problems earlier. When problems are detected early, the eService experts can inform the maintenance staff before problems have existed for long periods, mitigating the risk that a major failure would occur. It is hard to see little changes in the system, which is vital for the long term equipment monitoring. With continuous monitoring, the long term equipment condition can be better tracked allowing equipment replacements and maintenance work to be forecasted better. When the tool also pinpoints the type of the problem and its location, the maintenance team can go directly to the fouled machine. Adding that the tool has the ability to find the possible causes and the ability to make suggestions on how to repair the problem, maintenance staff can with this information send in the most suitable worker with the right tools. The tool also prioritizes the findings to a list of suggested repairs according to the estimated energy waste, maintenance priority or based on the comfort factors. This further makes the work of eService more efficient when the evaluation of what should be done first, can be done easier.

The basic eService tasks also include handling of alarms from the building automation. The eService experts cannot react to the smallest priority alarms, as there can be hundreds of alarms a day. The diagnostics received by the tool would give a fast and more in- depth analysis from the roots of the alarm, making it possible to react to a bigger amount of alarms in the same given time. eService personnel are also responsible for monitoring the functionality of the building automation by regular inspections using remote connection, further ensuring that the BMS is working energy efficiently and the indoor conditions are in order. The regularity of the inspections could be lowered if the tool was a standard equipment of eService, as many features of the tool support the inspections. The piloted tool can help with the monitoring of the indoor conditions by notifying the user if the pre-set values are slipping from the set values or if some of the pre-set values could be changed to more optimal setting. The tool also automatically checks the functioning of the control loops and informs the user if a loop is malfunctioning. The inspections cannot be however totally replaced by the tool, as some possibilities for energy savings demand the ability to combine information from different levels and knowing the special circumstances in the building.

The buildings are always audited when the basic eService or an EE savings project is started and they can be carried out also in other situations. The implementation of the tool, which demands several days to be completed, creates a problem with implementing the tool if the eService contract or an EE project is near its end. Risk could be too high to implement the tool, if the contract is not continued. However in the beginning EE projects or with long term eService contracts the tool can in most cases be implemented with low risk. When the tool has been implemented the tool will probably show to be useful with further auditions. The tool can provide a prioritized list of faults, which can be taken with to the audition and the pinpointed problems by the tool can lead the eService personnel directly to the sources of problems, making the whole auditing process more efficient.

14.2 How the tool could be improved to work even better as a tool for eService

The features of the tool have potentially a significant effect on the efficacy of the eService unit. The tool however is not optimally built as a tool for experts, but more for basic building operators. The tool is designed to be a software-as-a-service (SAAS) type of software and therefore there are several features that should be modified for the tool to be an effective tool for the eService unit.

The reports generated by the tool are clear and easy to understand, but the work of eService requires much deeper dives into the trend data, which is not currently possible from the reports generated by the tool. The graphics in the reports generated by the tool are quite small and non-interactive, which means that the graphs cannot be zoomed to get a closer look and the points which are present in the graphs cannot be selected. The graphics are used widely in the work of eService, so the non-interactive pictures, which cannot be zoomed, are not as useful as they could be. According to the eService experts; “The graphs have exactly the right things in them, but the pictures are too small and the scales are too large to have a real analytical value.”

Another challenge is the acceptance of a new tool, as there are vast amount of software already available for the eService unit. There should be a person in charge of the programs diagnostics, making sure the that detected problems are addressed and fixes are implemented. Otherwise the risk is that the diagnostics from the tool would just be left unchecked. As it is clear that the diagnostic technologies alone will not result in system efficiency improvements, since improvements can only be realized in the buildings where identified problems are corrected.

For the tool to truly reveal its potential, the service process of the eService should be built so that the first thing the eService expert does is open the piloted tool. In optimal situation, the tool would sync well with the already existing software, making the work of eService even more efficient by reducing the amount of different software in use.

14.3 Effects on the service quality

Valid and reliable measurement of service quality is vital to be able to accurately evaluate the quality improvements achieved by adding new tools, like the piloted tool, to the work of eService. According to the literature review if a tool such as the piloted tool is added to the work procedures of eService, it would be important to measure customer perceptions of quality before and after the introduction to see if the introduction of the tool has effects on the service quality. The SERVQUAL quality measurement tool is, according to the literature, the best tool to measure quality as it gives insights about how consumers judge quality. Knowing how consumers make quality judgements aids employers by suggesting how quality might be enhanced the most efficient way.

To measure the quality as literature suggests is not practical in the case of this pilot study. There are two main reasons why for example SERVQUAL would not give any meaningful results:

1. Firstly, the building in which the tool was piloted, was not under eService contract before the tool was implemented, so there is no data about the performance of eService before the introduction of the tool. With the missing baseline of service quality, there is nothing to compare the measured service quality to.

2. Secondly the building in which the tool was piloted was built in a way which pushed the building automation system to its limits. Therefore there were so many other problems in the building, that the reports from the piloted tool usually had not enough priority to actually generate actions. The reports had so low priority, that the operators in the building did not waste their resources on the little issues, when there were much bigger improvements achievable by improving the actual design of the building automation system.

Because of the challenges mentioned above, the five key dimensions of service quality are used as the base for the evaluation of service quality chances caused from introducing the piloted tool to the work of eService. The table 8 presents the dimensions, examples of the dimensions from the work of eService and the weight of each dimension. (Parasuraman et al. 1988).

The five dimensions	Weight	An example from the work of eService
The reliability dimension	32 %	Doing what was promised and doing it in time is the most important factor of service quality. Therefore for example providing monthly reports in time increases quality of the service
The responsiveness dimension	22 %	Answering the service phone promptly, without keeping customers waiting shows responsiveness and improves quality
The assurance dimension	19 %	eService providers are expected to be the experts of the service they are delivering, so high skill is important. Communicating the expertise is important, especially in the situation where the customer cannot see the remote services providing eService personnel
The empathy dimension	16 %	Listening to customers problems and finding out what extra could be provided for the customer, gives the customer a feeling that the eService personnel really care about the customer and are not just providing the service according to exact specifications
The tangible dimension	11 %	Taking account the appearance of uniforms, equipment, and work areas has a positive effect on the service quality

Table 8. The five dimensions of service quality.

When the eService personnel use less time doing manual checks to the system, the extra time can be used in multiple ways. The extra time could be used in increasing face-to-face time with the customers, which makes the customer feel like there is something actually happening, as it is harder to justify the on-going fees if the customer never sees the eService expert he has paid for. The extra time could be used to improve effectiveness also, which is further dealt when analysing the business potential of the tool. The tool could however improve the service quality without sacrificing the effectiveness improvements.

Adding new tools to the work of eService does not have effect on the service quality factors which are directly linked to the motivation and soft skills of the eService experts. The tool cannot change the basic attitude towards can-do, which would improve responsiveness and it either can make the service providers more empathic. The tool however could have some effect on the other factors.

Reliability comes from completing tasks in time and like was promised. The challenge in the work of eService is the limited time which is budgeted to a customer, which prevents the really deep dives to the customer's problems. This might lead to over promising and then underperforming as it is hard to set the expectations with your customer at a correct level, without detailed knowledge concerning the problem. The challenge is even clearer when the response time and responsibilities are strictly written in the service agreement. When the promises have to meet the specifications of the contract, the profitability of the contract deteriorates when the eService personnel have to spend a lot of time to fulfil the promises. It is easier to make accurate promises about performance when situation is simple. In complex problems, unexpected emergencies are more likely to appear and it is easy to underestimate the amount of work required to do the job.

Introducing tools, like the piloted tool, would have potentially significant effect on the reliability dimension. Firstly the tool would make the basic work of eService more efficient as was discussed in the chapters above. Secondly, the diagnostics generated by the tool would give extra information concerning the roots of the problems and of the solutions to the problem. Therefore the evaluations concerning the workload of a problem would become more exact, which again would lead to more accurate promises of performance increasing reliability.

The continuous monitoring of BMS could improve the responsiveness of eService personnel. Without continuous monitoring, the problems with for example indoor circumstances are noticed usually from the tenant complaints. With continuous monitoring, the emerging problems could be noticed earlier, so that in the best case the problem could be solved before complaints start arriving. Even if the complaints would have time to arrive, the problem would be known and already in solving process decreasing the time between the complaint and the answer.

Continuous monitoring of BMS would have impact also on the assurance dimension. Assurance builds from providing well-informed, knowledgeable service that is performed with competence and confidence. If the eService expert is already aware of the problem and has already worked on it before the customer calls, the eService expert is in much better situation in showing expertise. Another way of providing assurance to customers comes from building the customer's confidence in the eService expert's ability to help them. This is made easier by the diagnostics provided by the tool, as the eService expert has diagnostic reports informing when, where and why the problem has emerged and possible fixes to the problem. Therefore if the eService expert can tell the customer instantly what is a possible solution to the problem, the quality improves as the customer feels assured.

There lies potential increase in quality enabled by tools offering automatic analysis as has been discussed above. The potential downsides of introducing the piloted tool to the work of eService must be considered also. If the eService experts become overly confident on the analytics offered by the tool, there lies a potential risk. The eService experts cannot fully depend on the analytical machines performance, as the nonlinear and variable circumstances in which the building operates can never be totally covered. Therefore there are going to be faulty diagnostics and some problems are left unfound by the analytical machine. If however the tool is used like it was meant to be used, as an extra source of knowledge, there is little damage the tool can do.

14.4 **Business potential of the piloted tool**

Automated analytics of BMS has potential to bring more reliability to the operation of equipment in buildings. It also potentially increases the effectiveness of eService experts resulting in an increase in the competitiveness of the eService unit. In this chapter the business potential of the piloted tool is evaluated. The calculations concerning to the business potential are placed in a separate unpublished research paper [Mäkelä 2014]. The business potential of the tool was approached with three questions:

1. How much more effective could the work of eService be with the tool implemented to their work?

2. How much more quality could the eService personnel offer if they had the tool implemented in their work?

3. Could the implementation of the tool produce a “win-win” situation, where both the effectiveness and service quality would be improved?

The calculations concerning the business potential of the tool are based on an assumption that a part of the basic manual work of eService could be replaced with automatic analysis. The part that could be automated was calculated based on statistics from eService work and from interviews with the eService personnel. With the assumption that a part of the working hours of eService could be automated accompanied with the data concerning eService, the effectiveness factors of the tool were calculated and the answer to the first question was provided:

1. How much more effective could the work of eService be with the tool implemented to projects?

From the calculations [Mäkelä 2014] it became clear, that the tool would make the eService experts more effective. The eService experts could handle more contracts and still provide better service. Other option would be just to improve the margin on the contracts. Although the recent growth of eService suggests that the hours would be better spent in the new contracts. Calculations were also made to reveal the implementation cost of the piloted tool to a building with varying equipment [Mäkelä 2014]. The cost of the implementation depends on the amount of equipment and the complexity of the equipment. With the calculated implementation costs and with the approximation of hours that could be saved from the contract with the tool, a return of invest was calculated for the implementation costs. The experiences from the pilot study suggest that all of the features of the tool cannot be fully utilized right from the beginning. With the latter observation in mind, it was approximated that in the first month 10% of the automatic analysis capabilities are used, the second month 20%, the third 30% and so on. By this method a conservative evaluation for the return of invests was calculated [Mäkelä 2014].

The business potential of the tool in the EE projects was calculated based on an example EE savings contract. In the calculations the amount of quarterly hours used for the example EE project was calculated. The earlier observation that the work of EE- projects is heavily weighted towards the beginning of the contract was confirmed from the calculations, as the average hours spent on the first year were approximately six times bigger than the average hours spent in the last year. From the calculations [Mäkelä 2014] it became clear that if the tool was implemented in the new EE projects, the effectiveness of the eService experts working in the project would grow significantly. From the calculations it was also be observed that it might not be worth it to implement the tool in the EE projects which have been running for some time already, unless the project will probably continue as a basic eService contract.

The second question linked to the business potential was answered next:

2. How much more quality could the eService personnel offer if they had the tool implemented in the projects?

The quality improvements coming from using more time per customer mostly emerge from improving reliability of the eService experts. The reliability makes up for 32% of the quality produced, so the improvements on reliability really have effect on the quality. With more time the eService experts would have more time to dig into the customers problems and more time to use in the emergencies of the customer, without the feeling of needing to rush. The saved hours could be spent on increasing face-to-face time with the customers also. It is however unlikely that the saved hours would be put to increasing quality, as there are also ways the piloted tool could improve the quality without the extra hours.

The third question linked to the possibility of a “win-win” situation was answered next:

3. Could the implementation of the tool produce a “win-win” situation, where both the effectiveness and the quality of service would be improved?

The increase on effectiveness has been shown in the earlier chapters and it has become clear that adding tools offering automatic analysis to the work of eService is going to make the work of eService more efficient. The earlier results also suggest that there are ways to improve quality without needing to compromise the improvement of effectiveness. For example the diagnostics generated by the tool would give extra information concerning the roots of the problems and of the solutions to the problem. Therefore the evaluations concerning the workload of a problem would become more exact, which again would lead to more accurate promises of performance increasing reliability. The continuous monitoring of the BMS could also improve the responsiveness of eService personnel as the problems could be addressed faster decreasing the time between a complaint from a customer and the answer. Continuous monitoring would also have impact on the assurance dimension as when the eService expert is already aware of the problem and has already worked on it before the customer calls; the eService expert is in much better situation in showing expertise by suggesting instantly what is a possible solution to the problem. Therefore a “win-win” situation is possible to achieve if the possibilities of the piloted tool are used to their full extent and the piloted tool is adopted well to the work of eService.

15 CONCLUSIONS

The most important objective in this work was to find out how automatic analysis could be used in the work of Schneider Electrics eService. Therefore one of the primary objectives of the thesis was to identify the methods used for automatic analysis of BMS highlighting the best practices. The research came to a conclusion that the simpler qualitative methods can be easy to develop and apply but the results are not as reliable as with more complex qualitative methods, or the quantitative methods. It is therefore unlikely that even the most complex qualitative methods, expert systems, would achieve required levels of reliability. The models implemented with quantitative methods provide the most accurate diagnostics, but they can be overkill for most situations. The quantitative physical models however are usable in situations where there is a good theoretical background. Data based methods are among the most potential methods for automatic analysis of BMS from which the robust grey box models show the greatest potential. The methods used for automatic analysis have different uses and the methods can be used to supplement each other’s weaknesses. Therefore the developers of the tools that utilize these methods decide what methods are to become the best practises.

Characterizing the tools with different approaches on automatic analysis of BMS was the second main objective of this thesis. Four tools with different approaches on offering automatic analytics to BMS were characterized. The tools included ABCAT which is fast and cheap to implement but with quite simple approach on automatic analysis. The second tool reviewed, PACRAT, on the other hand can detect over fifty different types of problems making the approach much more complex and the implementation process heavy and costly. Third tool, WBD, has diagnostic capabilities which lie in the middle of ABCAT and PACRAT as WBD offers diagnostics, unlike ABCAT, and focuses on a few specific system diagnostics, unlike PACRAT for which the target is to find all of the problems in the system. The fourth tool, Infometrics, is the only tool that is purely service based and therefore there is no software offered to the customer. As the tools were characterized, it became clear that the different tools and the different methods which are used in these tools have different uses. The complex methods like expert systems are used in the PACRAT, and really light excel based analytics in the light tools like ABCAT. The research revealed that in order to successfully implement tools which apply automatic analytics, case specific rules and parameters should be avoided to make it possible to productize the tool. The most important result from the characterising of the tools however was the observation that the diagnostic methods used inside the tools are not the most important factor linked to the effectiveness of the tool. Rather the tool´s ability to motivate the users to use the tool is more important, as it is clear that the diagnostic technologies alone will not result in system efficiency improvements. Improvements can only be realized in the buildings where identified problems are corrected. The tools often cannot themselves motivate the operators to use them, and therefore it is recommended that there is a person put in charge of using the tool, ensuring that detected faults and problems are addressed and fixes are implemented.

eService is Schneider Electric's remote services unit delivering proactive energy efficiency services centred on providing service. In order to be able to evaluate the effects of automatic analysis to the service quality of eService, the backgrounds of service management were discussed, an introduction to service management was provided and the base for evaluating the development of the service of eService was created. The research on service management showed that service was once related only to face-to-face interactions between two people, one offering the service and the other receiving it. Today service domains and interactions are vastly more complex. It became clear that customers do not evaluate service quality solely in terms of the outcome of the interaction; they also consider the process of service delivery. Service quality is therefore a multidimensional construct encompassing all the aspects of service delivery, making the process difficult to assess and communicate. Therefore the only criteria available to evaluate service quality are subjective comparisons of customers' expectations to their perception of the actual service delivered. SERVQUAL was recognized as the predominating tool offering service quality measure, but the tool could not be used primarily because the building in which the tool was piloted was not under eService contract before the tool was implemented, so there was no data about the performance of eService before the introduction of the tool. With the missing baseline of service quality, there was nothing to compare the measured service quality to. Instead the five key dimensions of service quality, which were recognized from the literature, were used to assess the chances on service quality of eService unit.

Adding tools which offer automatic analysis to the work of eService seems to have great potential of making the work of eService unit more efficient. To study the usability of automatic analysis and to access the usefulness of one tool utilizing automatic analysis, a test pilot was conducted in a test building. The experiences from the pilot were not surprising. Automatic analysis systems were recognized to be less expensive than an engineer, always present, and more in-depth than an alarm. Continuous monitoring was seen as the most useful feature of the tool, as it directly answers to the challenge of noticing the problems soon, therefore reducing customer complaints and equipment breakdowns. The effects on the service quality were clear also. Introducing tools, like the piloted tool, to the work of eService would potentially have a significant effect on the reliability, responsiveness and to the assurance dimension which makes up for over 70% of service quality. Some limitations of the tool were identified, but as long as the users recognise that there are always going to be faulty diagnostics and some problems are left unfound by the tool, there is little if any damage the tool can do and instead the tool can offer great help. There were some limitations found from the piloted tool, especially with the graphical display. It was however identified that the limitations are not going to severely damage the usability of the tool.

15.1 Valuation of the research and future research

The research questions in which this thesis answers are:

- *How can the automatic analysis of BMS be approached?*
- *What is the potential, applicability and usability of tools offering automatic analysis of BMS in the work of eService?*
- *How does the introduction of automatic analysis effect on the service quality and effectiveness of eService?*

All of the research questions were answered and the main challenge of the research showed to be the digging of results from the pilot study. The implementation process of the tool could not be discussed as the information was not accessible, because a third party was in charge of the implementation itself. I wish I could have taken part to the implementation process more, so that there could have been more pilots and more hands-on work with the tool, which would have given a more throughout evaluation of the potential of the piloted tool. Now the potential had to be evaluated based on expectations and the experiences from a one pilot only. The pilot building and the piloted tool were also pre- selected by Schneider Electric so no comparison could be done concerning those matters. The pilot building was a modern LEED credited building, so there was a real challenge for the piloted tool to find energy savings. The pilot therefore showcased the piloted tool´s performance in an already energy efficient building. To further access the piloted tool´s potential, there could have been a second pilot in a building beginning with low energy efficiency, which would have given a better observation of the piloted tools performance in the EE projects which often are aimed at low energy efficiency buildings. As the piloted tool was pre- selected, there was no comparison regarding what tool could be the best suited as a tool for eService. However, as the tool was selected by Schneider Electric, there was a real commitment for testing the tool. The tool will also be used in the work of eService in the future, so it was essential to get experiences of this particular tool to better evaluate how this tool would effect on the eService work. Without the pre –selecting there could have been more difficulties in

Pilot study as a research method felt like a right approach for this type of research. The tool was used in the work of eService so there were some real experiences of the usability of the tool. The business potential of the tool could be done from real data from eService, although the calculations could not be published, which puts more value on the results of this thesis. There are also some limitations in the results from the pilot study. The results from the pilot study could have been more reliable if there was a baseline available from the building in which the tool was piloted. In the case of this pilot, the piloted building was quite new and there was no existing eService contract in the building at the beginning of the pilot. The evaluation of effects on the service quality could not be done like it was suggested by the literature as the baseline was missing. There were also some problems with the configuring of the piloted tool and therefore all of the problems could not be addressed when they emerged. The experiences from the pilot were however valuable in the future pilots concerning the tool.

There are new pilots already starting and the experiences from this pilot form a good starting point. The challenges with this pilot were recognized and the new pilots are launched in the buildings in which there is a good baseline available and a little less complex building automation system installed. The proper functioning of the piloted tool is also now familiar, so problems with the tool can now be more easily recognised.

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