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Building automation data visualisation and Complex Event Processing

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The purpose of this Master's thesis was to develop the ETSIVÄ Building Energy Data Inspector tool to visualise building automation data. Thus, the deviations from the data and faults of the building, by using the ETSIVÄ Building Energy Data Inspector tool were observed. By observing the deviations and building faults, it is possible to improve the energy efficiency of the building, and increase the comfort of its users.

Second, the suitability of Complex Event Processing (CEP) for analysing building automation data and the possibility to observe deviations that were found by using visualisations from the ETSIVÄ Building Energy Data Inspector tool were studied. CEP is a technological method for tracking and analysing streams of data to derive a conclusion and predict high-level events likely to result from specific sets of low-level factors.

The ETSIVÄ Building Energy Data Inspector tool was able to visualise the malfunctioning of an Air Handling Unit, and Complex Event Processing was found to be suitable to observe deviations of building automation data. CEP provides faster and easier approaches to analyse whole-building data quickly and also in real time.

Keywords	event, complex event, complex event processing, CEP, event processing language, EPL, FDD, building automation, demand-based, dashboard, visualisation, HVAC, meters, building service engineering systems, energy information

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Tämän opinnäytetyön päätarkoituksena on kehittää ETSIVÄ-sovellus, jolla pyritään visualisoimaan rakennuksen rakennusautomaation tietoa. Tämän lisäksi ensimmäisenä tutkimuskysymyksenä on pyrkiä havainnoimaan ETSIVÄ-sovelluksella rakennusautomaation tiedosta poikkeamia ja vikoja. Poikkeamien ja vikojen havaitsemisella ja niihin puuttumalla pyritään parantamaan rakennuksen toimivuutta, rakennuksen energiatehokkuutta, sekä parantamaan ihmisten viihtyvyyttä rakennuksessa.

Toisena tutkimuskysymyksenä työssä tutkitaan miten monimutkaisten tapahtumien käsittelijä (CEP) soveltuu rakennusautomaation tiedon analysointiin ja voidaanko monimutkaisten tapahtumien käsittelijällä havaita samoja poikkeamia, joita ETSIVÄ-sovelluksen visualisoinneista havaitaan. Monimutkaisten tapahtumien käsittely on yleiskäyttöinen tekniikka, jota käytetään suurten tapahtumamäärien käsittelyyn ja merkityksellisten tapahtumakuvioiden havaitsemiseen.

ETSIVÄ-sovelluksella pystyttiin visualisoimaan ilmanvaihtokoneen puutteellinen toiminta, sekä monimutkaisten tapahtumien käsittelyn havaittiin sopivan, tehtyjen tutkimusten perusteella, rakennusautomaation tiedon poikkeaman havainnointiin.

Avainsanat	monimutkaisten tapahtumien käsittelijä, CEP, rakennusautomaatio, tarpeenmukaisuus, visualisointi, energiainformaatio

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This Master's thesis is made as part of a research project between VTT and City of Helsinki Public Works Department. The main goal of the project is to create the ETSIVÄ Building Energy Data Inspector demostration tool. The role of the author in the research project was to develop the ETSIVÄ software in conjunction with another VTT software developer.

I would like to express my gratitude to Senior Lecturer Jarmo Tapio for his supervision and my instructors Janne Peltonen, Msc, and Teemu Vesanen, MSc, for their active support in this master thesis. I would also like to thank Sami Karjalainen, PhD, and Isabel Pinto-Seppä PhD for their comments and great support during the preparation of this Master's thesis.

I owe a special thanks to my wife Jenni and to my children Nooa, Aarni and Saana who encouraged me to complete this Master’s thesis.

Espoo, December 1, 2015

Mikko Tuomisto

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Abbreviations

AI	Artificial Intelligence
API	Application Programming Interface
AHU	Air Handling Unit
BAS	Building Automation System
C#	C sharp
CEP	Complex Event Processing
CO2	Carbon dioxide
DDC	Direct Digital Contorol
EPA	Event Processing Agent
EIS	Energy Information Systems
EPL	Event Processing Language
FDD	Fault detection and diagnostic tool
FCS	Field Control System
GUI	Graphical User Interface
HTML	Hyper Text Markup Language
HVAC	Heating, Ventilation and Air Conditioning
HVAC&R	Heating, Ventilation, Air Conditioning and Refrigeration
PHP	Hypertext Preprocessor
SaaS	Software as a Service
Tekes	Finnish Funding Agency for Technology and Innovation
UI	User Interface
VPN	Virtual private network
WWW	World Wide Web

1 Introduction

This Master's thesis aims to describe the background and motivation as well as present the objectives and research questions. In addition, a description of how the research is conducted is given. A detailed structure for the thesis is presented at the end of this chapter.

1.1 Background and motivation

World energy consumption is increasing rapidly. Global electricity consumption is estimated to double by the year 2030 and global energy consumption is estimated to double by the year 2050 [2]. Furthermore, the reserves of easily accessible and cheap oil and gas are running out. Today, some two-thirds of the global energy consumption is oil and gas. [1.]

The European Union is committed to reducing its overall carbon dioxide emissions at least by 20% by 2020 from the levels in 1990. Also, the European Union is committed to reducing its energy use by 2020 and increasing renewable energy sources by 2020. Finland is likewise committed to increasing the use of renewable resources from 28% to 38% [3]. Buildings account for 40% of the Finnish primary energy consumption and produce one-third of carbon emissions in Finland. The aim is, therefore, towards zero or near zero energy buildings. The new tightened Finnish building regulations obligate ventilation systems to operate on a demand basis. In addition, tightened building regulations obligate building construction and operations to be energy saving. Therefore, it is important that fault detection and diagnostics (FDD) software can handle energy saving. [4.]

The purpose of the FDD software is to increase the use of demand-based building energy solutions. Research indicates that if buildings use demand-based energy solutions, there is a 30–50% energy saving potential [5]. Since FDD tools mainly focus on energy measurement, variables other than pure energy consumption should be taken into account, or only partial optimization will likely be achieved. It is, however, important that energy is not saved at the expense of good indoor air quality. Building service engineering and FDD tools produce more information all the time, therefore the building sector is facing challenges. [6]

Complex event processing (CEP) is a technological method for tracking and analysing streams of data to derive a conclusion from the data. CEP is also used to predict high-level events likely to result from specific sets of low-level factors. In addition, CEP detects and analyses cause-and-effect relationships among events in real time, giving the possibility to also react to different kinds of scenarios in real time.

Management by knowledge no longer means simply relying on old data. More companies are finding future visions from various building data. The challenge is to modify the data so that it can be used as a basis for decision-making. The traditional way where information is added to a database and later accessed as reports, does not meet the business challenges of today. Real-time solutions are needed, or solutions as real-time as possible. Instead of first storing data and then putting queries to it, a query is created and data is then run through each query. With CEP, queries can be stored, instead of storing the data. CEP can process each event in real-time, and emit results when the query criteria are met, without actually needing to store data. Building automation and sensor information create large amounts of data that could be turned into knowledge with CEP. This knowledge could make buildings more energy efficient and improve indoor air quality of the buildings. Building users could feel better and be more productive.

The development of ETSIVÄ was part of a project called GreenICT-ToVa funded mainly by the Finnish Funding Agency for Technology and Innovation (Tekes). The objective of the GreenICT-ToVa -project was to create Software as a Service (SaaS) business and ICT-solutions. The aim was to visualise indoor building conditions and energy consumption to understand their reasons, and also to enable better control of buildings.

1.2 Research objectives and questions

The main objective of this Master’s thesis is to create a Building Energy Data Inspector demonstration tool (called ETSIVÄ) to be used by the City of Helsinki Public Works Department. The mission of the ETSIVÄ Building Energy Data Inspector tool is to decrease the energy use, and improve the performance of the buildings, and find inefficient spaces. In addition to the main objective, there are also two questions that need to be answered.

The research questions in this thesis are:

1) Can the ETSIVÄ Building Energy Data Inspector tool visualise building automation data to find anomalies that can save energy and increase the functionality of the building?
2) Can these anomalies found by the ETSIVÄ Building Energy Data Inspector tool also be found by using CEP?

The first of these further objectives is to find and visualise the automated building data of the City of Helsinki Public Works Department. The purpose is to find important information and anomalies, which could lead to energy savings and increased functionality of, first, case building and later more buildings.

The second additional objective is to study if the anomalies discovered by the visualisation mentioned above can also be found with the CEP method. CEP could yield new ways to find faster and easier approaches for the analysis of whole-building data quickly and in real time.

1.3 Thesis framework

The thesis framework is summarised in figure 1. The main objective, research questions and topics of the thesis are linked together. The main objective and research questions are described in red, the topics in blue.

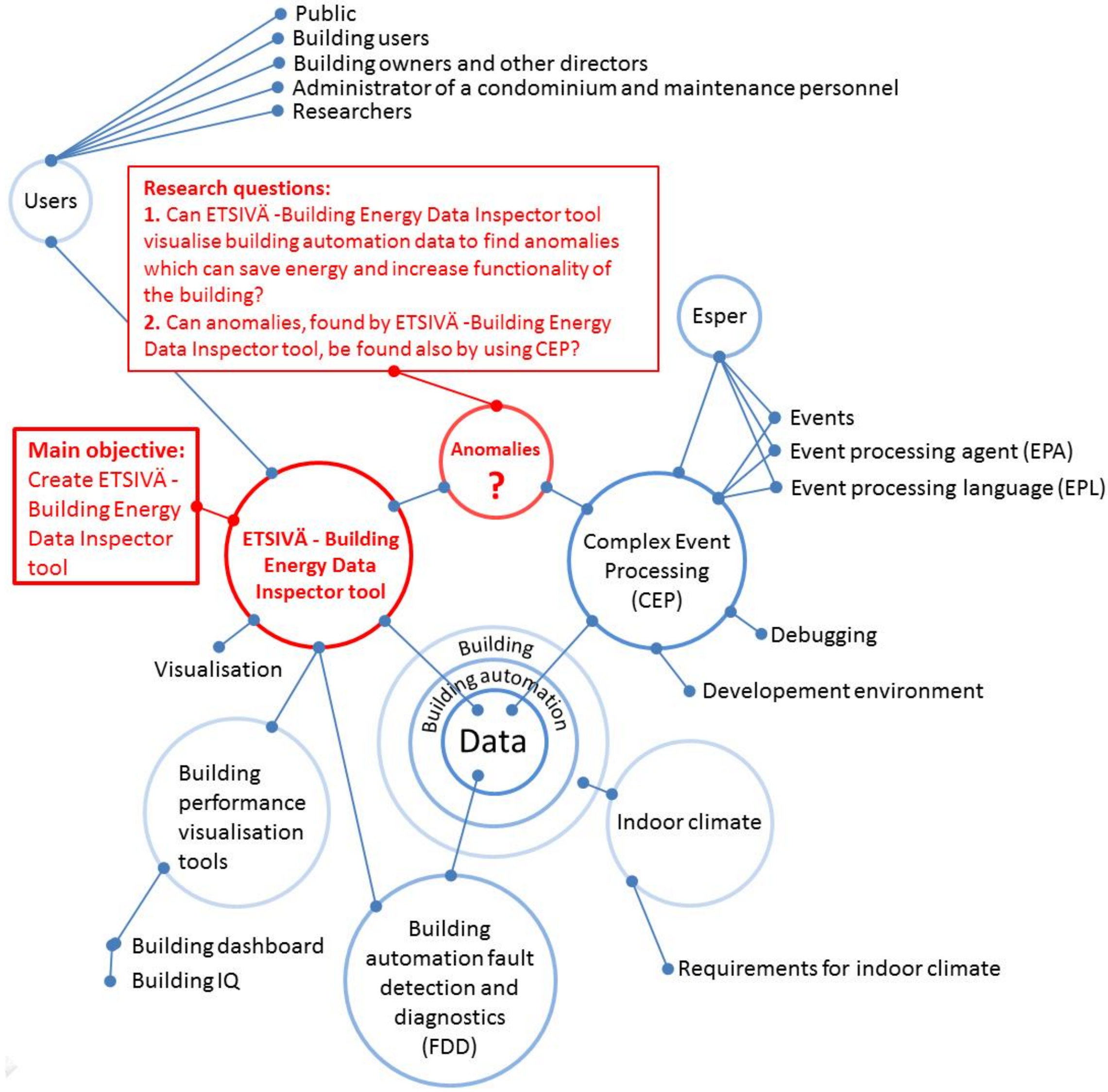

Figure 1. Framework of the thesis

1.4 Risks

The risks the Master's thesis project might face are a risk for staying in the schedule and obtaining sufficient data may be difficult. Also, building automation data can be too narrow to signal complex events. Furthermore, finding available information, both written and oral, from complex event processing may be difficult. Also, it might be difficult to set up a real-time data stream between VTT and the City of Helsinki Public Works Department. Moreover, a limited time schedule for producing the ETSIVÄ Building Energy Data Inspector tool and preparing the thesis presents challenges.

2 Literature study

In setting out the research environment below, first the indoor climate is defined. Then I will consider the significance of building operation and maintenance, as well as the relevant actors involved in this field. To end this Chapter, an overview of Complex Event Processing (CEP) will be provided.

2.1 Indoor climate

The indoor climate of a building consists of many different factors. In addition to indoor air quality and the building's thermal conditions, building lighting conditions and acoustic conditions affect indoor climate. Air quality refers to different kinds of impurities in the air. Thermal conditions encompass the air and surfaces, humidity, and the movement of the air. Building lighting conditions are formed from luminance, glare and colour reproduction. And acoustic conditions refer to the noise level of the building. Indoor climate factors are presented in figure 2. [7.]

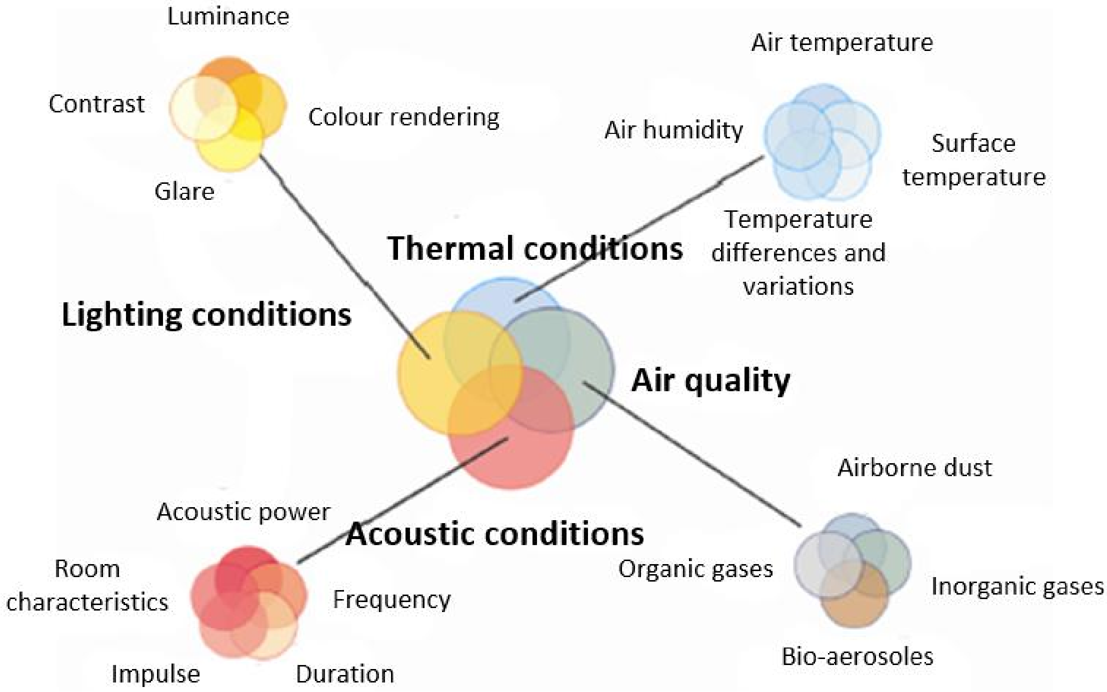

Figure 2. The four elements of indoor climate [7]

Indoor climate has a big impact on human wellbeing, since people in northern Europe spend on average 90% of their time inside [7].

The indoor climate classification is defined in the national Building Code of Finland section D2. The building is designed and constructed as a whole so that in the occupied zone, a healthy, safe and homely indoor climate is achieved under all common weather and operating conditions. The indoor air quality classification published by the Finnish indoor air quality association includes instructions on how to achieve good indoor air quality. Indoor air quality limits are not regulations, they are recommendations. The Finnish indoor air quality association divides air quality into three classes: S1, S2 and S3. S3 includes the regulated minimum level set by the Finnish building code, S2 defines a good indoor climate, and S1 defines individual indoor climate. The classes are defined as follows: [8.]

> **S1: Individual indoor environment**
> The indoor air quality of the space is very good and there are no detectable odours in the environment. There is no damage decreasing the quality of indoor air in the spaces or structures connected to indoor air, and there are no sources of impurities. Thermal environment is comfortable, and there is no draught or overheating. The user of the space may individually control the thermal conditions. The space has a very good acoustic environment in view of its use and individually adjustable lighting supporting good lighting conditions.
>
> **S2: Good indoor environment**
> The indoor air quality of the space is good, and there are no disturbing smells in the environment. There is no damage decreasing the quality of indoor air in the spaces or structures connected to indoor air, and there are no sources of impurities. Thermal environment is good. There is usually no draught, but overheating is possible on summer days. The space has a good acoustic and lighting environment in view of its use.
>
> **S3: Satisfying indoor climate**
> The indoor air quality and the thermal environment of the space meet the minimum requirements set by the building codes. The target and design values for individual factors can be selected from different categories, or, if necessary, the value of a factor can be specified separately. [8.]

The target curve of the temperature is presented in figure 3. Operative temperatures are used. Operative temperature is the isothermal space temperature, where the combined effect of radiation and convection heat flows on the body is the same as in the reviewed facility space [9.].

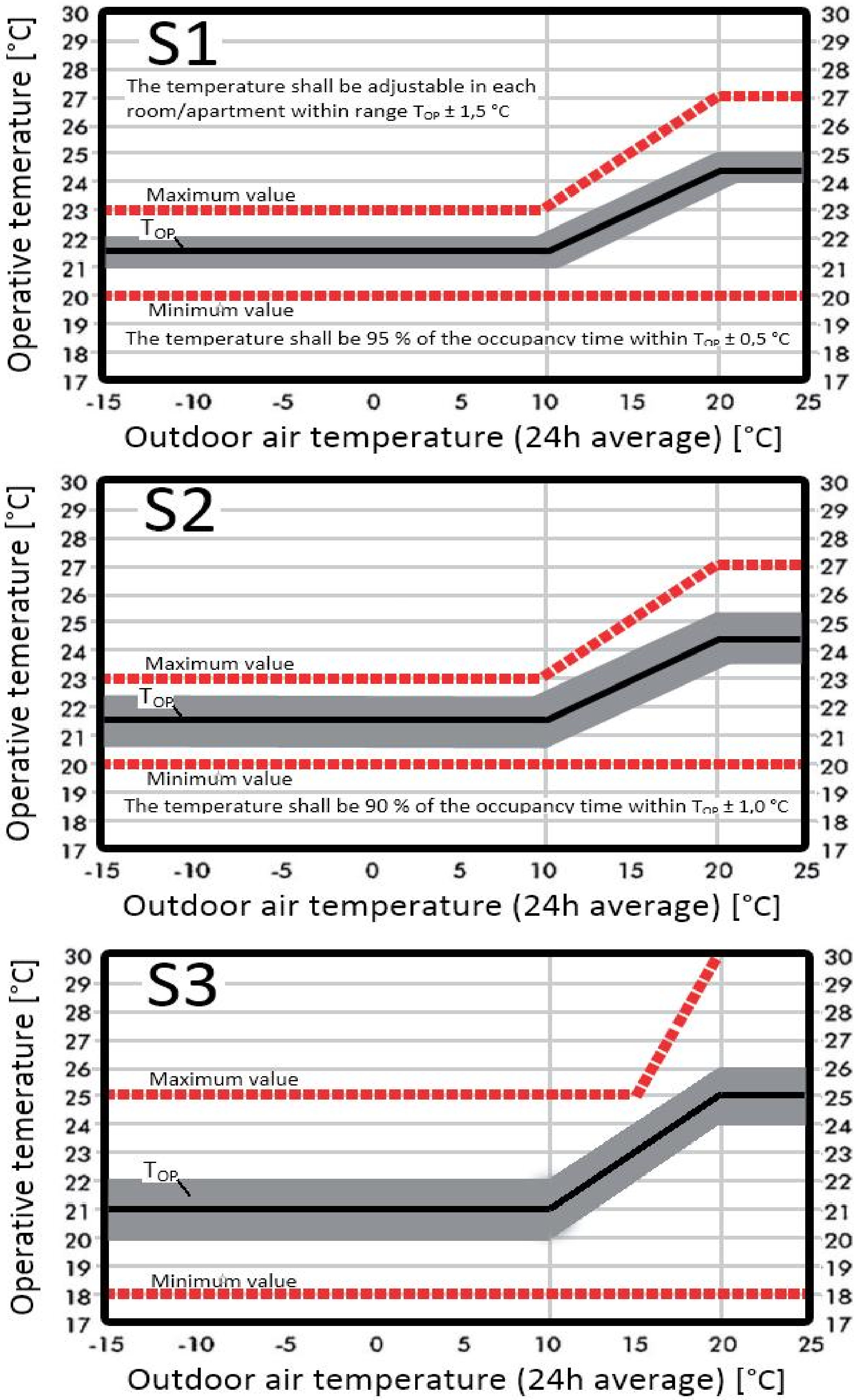

Figure 3. Indoor classification target operative temperature values for the different classes: S1, S2 and S3 [8].

Carbon dioxide content values for the three (S1, S2 and S3) indoor classes are presented on the first line of the table 1.

Table 1. Maximum values set in the indoor climate classification [8].

	S1	S2	S3
Carbon dioxide content [ppm]	<750	<900	<1200
Radon content [Bq/m3]	<100	<100	<200
Condition stability [% use of time]			
- premises and educational facilities	95%	90%	
- dwelling	90%	80%	

Air velocity target values, defined in the indoor air classification, are presented in table 2 below.

Table 2. Maximum values for air velocity set in the indoor climate classification [8].

	Velocity of the air		
	S1	S2	S3
t_{ilma} = 21 °C	<0.14	<0.17	0.2 (winter)
t_{ilma} = 23 °C	<0.16	<0.20	
t_{ilma} = 25 °C	<0.20	<0.25	0.3 (summer)

2.2 Building services engineering systems

Traditionally the term building services engineering systems refers to HVAC (heating, ventilation and air conditioning) systems and electrical engineering systems. Nowadays building automation gathers information from subsystems and controls the whole system. Building automation can intensify the function of the building significantly and increase the energy efficiency of the building.

Today’s modern buildings are full of different kinds of HVAC systems, which also means that HVAC systems play a key role in determining the energy efficiency of a building. The computational life cycle of a building is 50 years. 80-90% of the energy consumption occurs during the servicelife of the building. Although the future trend is towards zero energy buildings by the year 2020, the lifespan energy consumption for a building is expected to decrease. The construction time is a small fraction of the whole building's lifetime. Still the most important choices are made during the construction phase, which affect the building's energy consumption for the whole lifetime of the building. The lifetime for the building service engineering systems is about 20 years. Thus, the choices that are made during the construction of the building limit the options of choosing new technical building service engineering systems to be implemented in the building's future. [10.]

2.3 Building automation system

A building automation system (BAS) is a tool to control the indoor climate, lighting and safety of the building. A BAS controls most of the technical devices and tries to minimize the energy use, noise and other disadvantages caused by technical devices [11].

Månsson & McIntyre describe the functions of the BAS as follows [12]:

- Automatic switching on and off
- Optimisation of plant operation and services
- Monitoring of plant status and environmental conditions
- Provision of energy management information
- Management of electrical load
- Remote monitoring and control

Building automation systems can be divided into two basic cases: centralised and decentralised systems. A centralised system is divided into hierarchical levels, where the upper level takes the responsibility for lower level functions. Today, intelligence is often devolved to a building automation substation and the control room task is to combine the information from various substations. The term for this kind of a system is Direct Digital Control (DDC). In a decentralised Field Control System (FCS), on the other hand every sub-process is intelligent and operates independently, but sub-processes communicate together and can exploit each other's information. Modern building automation systems include DSC and FCS system hybrids. System structures are shown in figure 4.

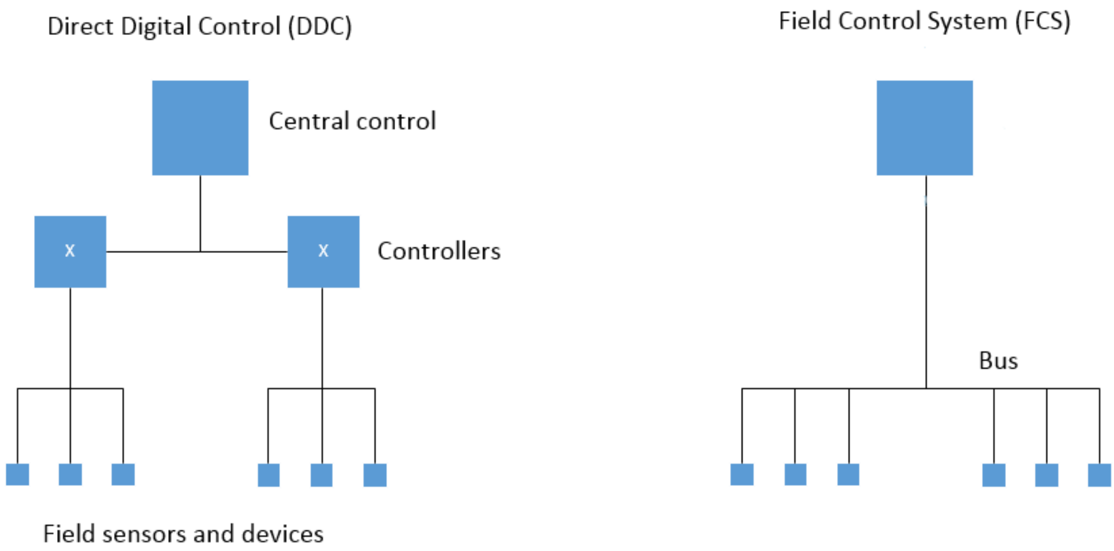

Figure 4. Two different methods to implement a building automation system [13].

At the top level, both systems have one central control or many central controls. The central controller has access to all measured values and can control all processes. A central controller registers the alarms of non-functioning devices, abnormal measurement values, as well as informs about the functionality of the building through different kinds of reports. Above the level of the control room there may be analytical tools or dashboard applications, which handle the data collected by the building automation system and process it into a form that is easier for people to understand. [13.]

Controllers are the most important units, since they process data and take care of equipment control processes. Controllers work between central control and field sensors and devices. All field devices are connected to controllers and controller are connected to central control.

At the bottom level there are the field devices: different kinds of sensors, valves and actuators. Field devices are also divided into intelligent and non-intelligent field devices based on whether they can process information or not. Unintelligent field devices are connected directly to the lower centre with a twisted-pair cable, where measurement information responds to changes by means of voltage and current signals. The lower central processor will process the signals and transform them into physical quantities. In addition, non-intelligent field devices are connected to other sensors and lower centrals by the means of a fieldbus. Intelligent field devices transform measurements into physical quantities and send the information by the means of the fieldbuses to other equipment. Sensors can also send information about any detected errors and their status. [13.]

2.4 Building automation fault detection and diagnostics

Building system problems are usually detected as a result of occupant complaints or alarms provided by building automation systems [15]. Finding the root cause of problems or faults might not be an easy task. The primary purpose of a building automation system is to control the building systems and also to provide sufficient assistance for building maintenance in detecting and diagnosing problems. Building automation systems have limited capabilities in managing and visualising large amounts of data and it is time-consuming to find the causes behind occupant complaints and equipment failures [16]. Since building automation systems have limited capabilities to manage and visualise large amounts of data, building maintenance may perform inappropriate re-adjustments, leaving the causes unaffected. This can lead to increased energy consumption and uncomfortable indoor conditions. Also building processes and systems will become more complex in the future as we aim towards higher levels of energy efficiency. Fault detection and diagnostic tools can help building management with maintenance and optimisation as well as in detecting performance problems and giving instructions about corrective actions. [14;17;18]

Fault detection is a traditional step in implementing energy efficient changes to a building. Traditionally fault detection is based on conforming to limits or on checking important process variables, such as temperature and pressure. Fault detection is utilised if the limits are exceeded. It is assumed that operators will take action to protect systems from greater damage. A software application recognises when a system is operating correctly, but performing at a level that is sub-optimal compared to its target values. To set the limits for actions, compromises have to be made between the detection size for abnormal deviations so as to avoid false alarms caused by the normal fluctuations of variables. Finding the underlying cause of a fault is difficult, since alarms are based on a threshold violation of one or more variables. However, CEP can feasibly be used to identify these alarms easily, in real time, from the data [14;19]

Fault detection and diagnostics (FDD) tools use more sophisticated methods to detect and diagnose performance degradation and faults. FDD tools collect data from some process components and process the data and thereby identify faults, find reasons for faults and give instructions on how to correct faults [18]. FDD tools help to analyse and organise large amounts of data and efficiently extract useful information [16]. With FDD tools, it is possible to find faults that would normally go unnoticed. Thus, maintenance can be warned before problems develop enough to affect indoor air quality or building energy efficiency.

Fault detection can be divided into three sequences [18]. The first step is fault detection, the second step is fault diagnosis, and the third step is evaluating the fault and eliminating the cause. Fault detection can be done manually or automatically. FDD tools differ from analytic software and trouble-shooting-tools by automating the fault detection process and by reaching conclusions from empirical data. These tools provide assistance in diagnosis, for example, by plotting data in various ways. Thus, performance problems can be detected and diagnosed by an expert. Automation reduces the time required to find a problem, thus reducing costs. [21.]

Few economic evaluations of the benefits of FDD tools have been made. The first study [22] showed that an FDD tool, which was tested in seven buildings, was able to find faults in every one of the buildings. Faults that were discovered in the buildings included, for example, incorrectly calibrated sensors, stuck dampers and inadequate ventilation. The estimated annual cost impact was between USD 130 and USD 16 000. In a second study [23], automated fault detection and diagnostics of rooftop air conditioners were tested. Estimations were made on the potential FDD savings, and preventive maintenance costs were considered as part of the economic assessment. Calculations estimated that conservative estimates of the lifetime net savings ranged from USD 4000 to USD 10 000. Annual net savings ranged from USD 400 to USD 1000. The payback time for the FDD tool in these scenarios would be less than one year.

FDD tools have been an active area of research and development, for example, in the process controls, automotive and manufacturing industries, and in national defence. Over the last decade, efforts to bring automated fault detection, diagnosis and prognosis to HVAC&R have failed. Most FDD tools work well when a single dominant fault occurs in the system, but if multiple faults occur simultaneously, many methods fail to detect or diagnose the reason of the faults. [14;24;25]

Many different kinds of algorithms and advanced methods, such as artificial intelligence, pattern recognition, fuzzy logic and neutral networks, have been developed during the recent decades to solve complex problems in information processing. These methods have often demonstrated remarkable performance, but still often fail to proceed into real use. With more research, CEP could penetrate into actual use, where it could provide new, faster and easier methods for analysing building automation data in real time. More knowledge is needed about these kinds of techniques, otherwise there is a possibility of them failing in real use, because these kinds of solutions are seldom transparent to the user. In addition, it is typical that an expert in these methods needs to participate to the maintenance of the software, once these methods are taken into use [26]. For example, the time of installation and the tuning time to set up an FDD tool is one week [27]. Therefore, the cost of setting up and tuning an FDD tool can be a significant investment.

2.5 Visualising energy information with a Fault Detecting and Diagnostic tool

Information systems in building operation and maintenance have focused on system performance and assessing the building performance, but not on the prognostics of single pieces of equipment or building conditions. The aims of using FDD tools have been to reduce energy costs, improve indoor air quality, and optimise building operation.

In this chapter, different kinds of tools used for assessing building performance are discussed. The optimal features of Fault Detecting and Diagnostic (FDD) tools are discussed at the end of the chapter, when two commercial tools are presented.

Sometimes FDD tools are referred to as Energy Information Systems (EIS). Energy Information systems (EIS) refer to software, data acquisition hardware, and communication systems that collect, analyse and display building information so as to reduce the energy use of the building and the associated costs [28]. There are many reasons why Energy Information Systems are viewed as a promising technology. It is known that there is often a large gap between the building energy performance as designed and the actual measured energy consumption. Some EIS provide building anomaly detection, although automated FDD functionalities at the component level are not typical. EIS is described in figure 5. [29;30]

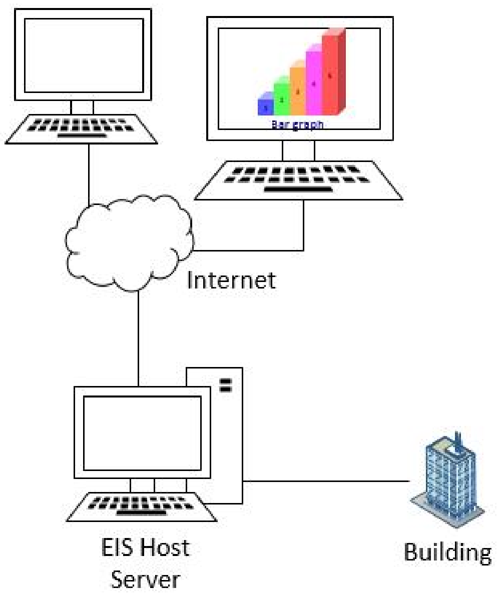

Figure 5. Basic Energy Information System [28].

One way to create a visualisation of building performance is to use an information dashboard. An information dashboard is a single screen display that presents the user with the most important information. With the information dashboard, the user can monitor situation of the building. [31.]

A good tool from the user's point of view has different user interfaces for managers and technicians. The tool should help users instead of replacing them and be easily modified. Furthermore, the tool should be easy for users to understand. In addition to these the tool must do what the tool promises to do, for example, reduce the energy costs or to increase the indoor comfort, or to reduce the maintenance costs. [32.]

Other studies suggest that the tool should only show important and final information. The tool should also use practices, terms and units that the user is familiar with. Furthermore, the tool should explain all parts of the graphs and use graphical elements. Pie graphs should be used only in special cases. In addition, the tool should provide a possibility to compare the present values to the history (yesterday, last week or last year). [33;34]

FDD tools should generate alarms, when the tool detects a fault, as well as provide a synthesis report with the ability to drill down deeper into the data, to find out more details [32].

A more recent study [37] has looked at user needs and preferences regarding building information visualisations, as well as information practices. Visualisations should include a high-level overview with drill-down capabilities and integration of energy visualisation features with data analysis. Furthermore support for normalisation and energy benchmarking and compatibility with existing building automation systems were considered important.

Stephen Few [31] has listed six common mistakes made in FDD tools:

- The page is bigger than the screen
- The information presented is not important
- Information is presented in a wrong way
- The most important information is difficult to find among other information
- Redundant visualisation confuses the layout
- Colours are used in a wrong way or there are too many colours. [31.]

Many tools have the ability to handle a single building. Many tools are also able to handle all many buildings. Some FDD tools can even to control building automation, but not always. User privileges can also be restricted.

Marini [38] classifies users in five different FDD user groups: the public, building users, building owners and other directors, administrator and maintenance personnel of a condominium, and researchers that the FDD tool should address. The FDD tool should give different views to different user groups and show information according to the needs of the user group:

- **Public:**
  The members of the general public are interested in seeing an overview of the building performance and the building owners interest in environmental issues. The main indicators are enough for the public. If the building contains many companies, the company details should be shown separately. [38.]
- **Building users:**
  Building users are usually non-technical so they do not have specific knowledge of how the building works and how technical aspects affect the functions of the building. Building users are interested in exact information about their personal conditions, the conditions of their own group or their own company. Building users are an important group, since they are responsible for the electricity use of the building, but must only rely on the FDD for information. [38.]
- **Building owners and other directors:**
  Building owners are interested in the key figures of the building, especially in comparison to other buildings they own. Building owners are also interested in comparing a building at a national level. Most owners usually have a non-technical background, so information needs to be easy to understand. Preferably, the owners should be given financial information. It is important for owners to compare the weekly, monthly or yearly consumption with that of previous years so that they can see the direction of the development. [38.]
- **Administrator of a condominium and maintenance personnel:**
  Administrators and maintenance personnel of a condominium have a technical background, therefore they can be shown more specific information. Their main goal is to find potential problems and identify errors and alarms in a building's by using the FDD tool. They are interested in the running times of ventilation machines, the electricity use of lighting, and overall information for each specific section. They are interested in real-time information, as well as information covering longer periods. [38.]
- **Researchers:**
  Researchers are similar to the previous group in terms of their needs. Researchers are interested in the same information as administrators and maintenance personnel; they are seeking to develop better systems and to gein in-depth understanding on how different factors affect to processes. [38.]

FDD tools are not new innovations. There is a long history of their development towards the market adoption. Different kinds of FDD tools for visualising building information have been launched several times, but despite numerous attempts, none of the software has survived [39]. However, well-designed FDD tools do have a place and the current FDD tools should not be judged based only on the failures of their predecessor software. In today's world, where sources of cheap energy are decreasing and networked systems and developed technologies are increasing, FDD tools are likely to be here to stay.

A web-based user interface, for example, a dashboard application, is a good way to affect the energy consumption of users. Most people consider a web-based system to be the best. It is important that the user can modify and personalise the user interface to fit their preference, since users are individuals. Studies have shown that mobile phones [40] have not proven themselves to be a good web-based user interface for visualising energy consumption information. On the other hand, a well-designed web-based user interface is accessible also with a smartphone [40].

2.6 Different ways to reduce building energy consumption

People recognize the importance of observing their own electricity consumption and thus affecting the total consumption. Great importance is attached by 63% of households to observing their own electricity consumption [41]. However, people are fundamentally lazy and not willing to find the optimal solution if they can find an easier solution with minimum effort. In particular, if people do not know what is optimal, they are satisfied with a moderate solution, if the solution is found to be easier or faster to use than finding the optimal solution. [42.]

Real-time metering, together with real-time information delivery to the uses of electricity turned out to be an effective way of reducing electricity use. In an average a 10% energy saving is achieved only by showing real time measurements and showing simple energy saving advice. The influence of the oil crisis at the end of the 1970s is still seen in the usage habits of building users, since many building owners have lived through the oil crisis and their habits have not changed since [43]. However, good information does not always lead to good results. For one reason or another, the potential energy savings for a system are not believed, although the information system can indicate a clear error. Maintenance staff can be too busy or they can miss an overall understanding regarding the operations they are performing. The operations may be too complex and time consuming, and the maintenance staff may, therefore, settle on fixing major problems when they occur. [14;54]

It is important to inform the users of the building about different factors that affect energy consumption. Sami Karjalainen asked the test persons in his research about their actions to reduce energy and in many cases their attention was focused on operations that had minimal impact on energy saving. It is important to present different elements that impact energy saving to the user. The information should be presented to the user in units that are easy to understand, for example as monetary sums, since users do not necessarily understand engineering units like watt (W) or kilowatt-hour (kWh) [34]. It is possible to save energy by shutting down the equipment of the building, but it is not wise from the perspective of the health of building users, safety, and the integrity of building structures.

Sami Karjalainen and Olavi Koskinen’s study shows that facility users do not understand how they can affect the indoor climate conditions of their workstation. Even electrical switch locations or their functions may be unknown, not to mention more difficult control options. Sami Karjalainen has suggested that easy-to-use building technology could bring about a revolution, similar to that brought by easy to use Apple products in computer and mobile markets. The best results were found in the study with a group that received real-time measurement data compared with the consumption in the previous year and also with a group of similar sized apartments in the area. [44;45]

The EC research project EEPOS found the following typical malfunctions that influence the energy efficiency of HVAC systems:

- Simultaneous heating and cooling
- Malfunctions of the regulation systems
- Manual switching off and other interventions
- Missed maintenance
- Malfunctions of the hydraulic system
- Low efficiency factor. [46.]

Studies have shown that people like to compare their own energy consumption with that of people in the same area. Social media (e.g. Facebook, Myspace and Twitter) can present new channels for saving energy in a competitive way. [34.]

2.7 Example of building performance visualisation tools

In the following paragraphs two current building performance visualisation tools are presented. The product descriptions are based on materials taken from company websites. It should be remembered that companies can give a biased presentation of their products, since these materials are written from the marketing point of view and therefore highlight their positive aspects. [30.]

A example of building visualisation tools is the Building Dashboard in figure 5 below. The Building Dashboard has a leading market position in the United States. The tool is an interactive website that provides real-time information feedback: it teaches, inspires behavioural change, and saves energy and water in the buildings at the same time. The Building Dashboard can gather data from the automated systems, data loggers, webcams and utility meters of the building. The building dashboard visualisations are presented in the figure 6. [47.]

Figure 6. Building dashboard overall view for user [47].

A second example of the visualisation of building information is BuildingIQ. This software uses advanced algorithms to automatically control HVAC systems, while maintaining or improving comfort. BuildingIQ is accessed through a web interface and it is intended for building owners, maintenance personnel, and consultants. Figure 7 Illustrates the operation of predictive algorithms that effect the HVAC systems. Figure 7 also shows a typical building on a typical day. The blue line shows the power levels according to the existing settings on the Building Management System. The red line shows the power levels controlled by energy optimisation software, which has been tailored to the specific weather and the utility rates. The green line shows the outside temperature and the light blue line illustrates the inside temperature. [48.]

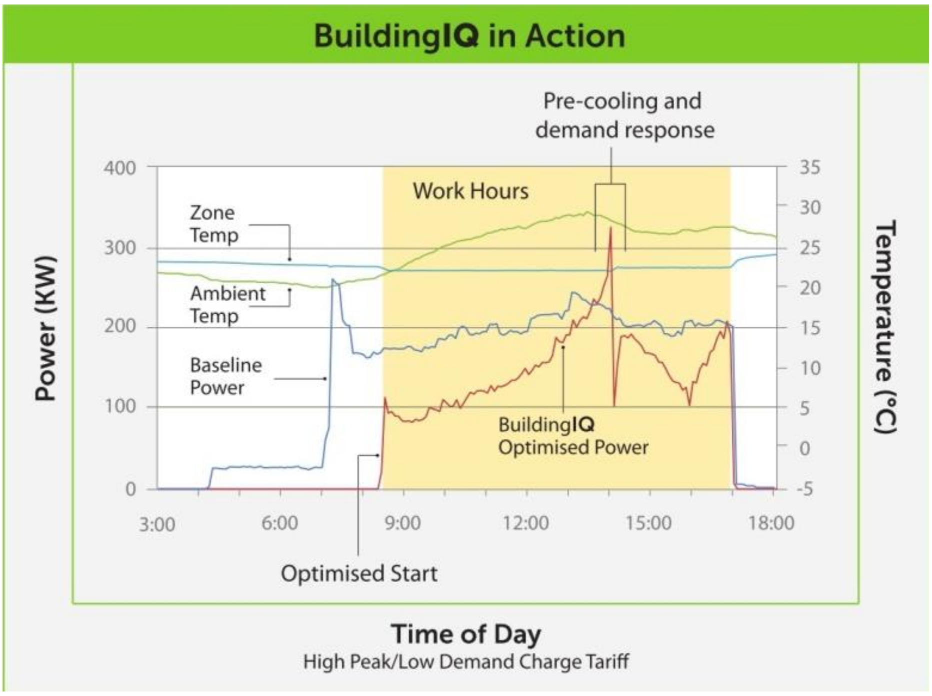

Figure 7. Predictive algorithms for HVAC systems in a typical building on a typical day [49].

2.8 Complex event processing

Complex event processing (CEP) refers to the use of technology to predict high-level events likely to result from specific sets of low-level factors. CEP detects and analyses cause-and-effect relationships among events in real time, and when necessary, reacts to different kinds of scenarios in real time. A significant contribution to CEP was made by David Luckham [50], in his book ‘The Power Of Events’. Since it is both an early and complete work, much of the outline for CEP detailed in this thesis is derived from this seminal monograph.

CEP emerged at the beginning of the 1990s from David Luckham’s research projects ‘Rapide and CEP’ conducted at Stanford University, brought together in the publication [51]. Today, CEP is generic technology, since most information systems are driven by events. For this reason, CEP can be applied to a multitude of business areas. Below some of applications where CEP can be applied:

- Business process automation utilising the Internet and electronic marketplaces
- Computer systems to automate the scheduling and control of anything from fabrication lines to air traffic
- Network monitoring and performance prediction
- Detecting attempts to intrude into computer systems or attack them [50]

All listed applications are run in real time since CEP entails real-time event processing. For example, intrusion detection applications can detect intrusion instantly by using CEP.

Next paragraphs define in more details event, complex event and causality and also how the event processing and traditional computing separate from each other. This is facilitated with the examples. At the end of the chapter, EPA and EPL are defined.

2.8.1 Difference between event processing and traditional computing

The difference between event processing and traditional computing is that event processing answers questions in real time. Traditional computing utilises static data, for example, a customer data table or transaction at a retail store. Database-oriented computing helps applications to answer the question: “How many cars were sold in European stores last month?”

Real-time computing requires event processing that can handle streaming events. Streamed events are dynamic data, for example, the streaming of enterprise events allows a business to recognise the pulse of operations as the events travel through the IT network. Patterns can be identified with event processing, which allows for instant decisions while patterns still matter. [52.]

2.8.2 Examples of complex event processing (CEP)

An example of complex event processing is a car with various sensors. CEP can be used to detect complex situations. For example, a car is moving and the pressure in one of the tyres drops from 50 psi to 30 psi in the space of 10 seconds. The event is detected perhaps because of too quick a pressure loss or because the difference in the values between each event were larger than the set limit value. The changed situation generated the event “EmptyTire” and immediately alerted the computer to assist the driver to stop the car safely.

In addition, detected situations can also be combined with various events in more complex situations. For example, if a car tyre blows which results in the car leaving the road and colliding with a fence next to the road and the driver is pressed against the seat belts, a series of different situations are detected. The combination of ‘EmptyTire’, ‘RapidAcceleration’ and ‘SeatBeltTightens’ are detected over a very short period of time and that creates a new event that is recognised as ‘Collision’. Even though there is no direct sign that a collision has occurred, the combination of events allows a new event to be created to signify the detected situation. [55.]

This simple example does not capture the complexities of real-life conditions. The example is given rather to demonstrate how CEP can be used to detect events in real time.

2.8.3 Events, complex events and causality

David Luckham definies an event as an activity that has happened in real life or in an information system. An event can also occur as a result of other events. An event has three aspects: [51.]

- **form:** The form of an event is an object
- **significance:** An event signifies an activity
- **relativity:** An activity is related to other activities by time, causality and aggregation. [51.]

An event can be thought of as an object that has special attributes or data components. The attributes depend on what the event signifies, thus every event has a unique identifier field, a timestamp or a time interval when the activity happened, and a causality attribute that provides a way to identify its causal history. Event processing deals with the relationships between different events, and this is why it differs from message processing. [50;51]

A complex event is an aggregation of other events, which are called members of events. An aggregation is the relationship between a complex event and its members. Events that combined in are complex events can be simple events or complex events. In an event processing application, complex events are events at a higher level than the levels of the members of events. When going to a higher level, events are filtered, constrained and aggregated. The number of events get smaller and the events, likewise, become more abstract. [51.]

Causality is a dependence relationship between different activities in a system. An event depends on other events if it happens only because other events have happened. If event B depends on event A, then A is said to have caused B. Event A and event B are independent if neither caused the other. Events can be traced by following the causality attributes. The events that can be found by following causalities are referred to as drilldowns. [50,51]

2.8.4 Event processing agent (EPA)

An event processing agent (EPA) is a software module that processes events. An EPA is an object that monitors the execution of an event and detects event patterns. It can monitor event executions online at the same time as the events are being created, or offline using previously collected data. When the event pattern rules find matches, input event body actions are performed. The actions can generate new output events, change the Event Processing Agent's local variable, or interact with other IT-systems.

Three basic classes of EPAs have proved useful in CEP applications:

1. **Filters:** A filter outputs the partially ordered sets of events when the input matches its pattern.
2. **Maps:** Maps are used to specify event hierarchies. They use event pattern rules to aggregate partially ordered event sets into higher-level events.
3. **Constraints:** Constraints verify that the system is in an adjusted state. [51.]

2.8.5 Event processing language (EPL)

The Event Processing Language (EPL) is a generic term for a programming language that enables the detection of complex events in a system. Most EPLs are similar to the Structural Query Language (SQL) with clauses like SELECT, FROM, WHERE, GROUP BY, HAVING and ORDER BY. EPL statements are used to derive and aggregate information from streams of events, and to join or merge event streams.

Some of the categories of event pattern matching:

- **String pattern matching:** For searching simple, usually single, events.
- **Single-event, content-based matching:** For searching single events, where the content of the event determines the success or failure of a potential match
- **Multiple-event matching with context:** For matching patterns of several events. [53.]

The example codes in this section are mode with the open source CEP engine Esper-language. The first EPL example computes the average prices for the last 60 seconds of stock tick events, as listing 1 illustrates. [53.]

```
select avg(price) from StockTickEvent.win:time(60 sec)
```

Listing 1. EPL example computes average prices [53.]

The second EPL example returns the average price per symbol for the last 1000 stock ticks, as listing 2 illustrates [53].

```
select symbol, avg(price) as averagePrice
    from StockTickEvent.win:length(1000)
group by symbol
```

Listing 2. EPL example returns average price per symbol [53.]

The third example is more complicated. The example joins two event streams. The first event stream is a fraud warning event concerning the last 60 minutes and the second event stream is a withdrawal event from the last 60 seconds. These two streams are finally joined to an account number, as listing 3 illustrates. [53.]

```
select fraud.accountNumber as accntNum, fraud.warning as
warn, withdraw.amount as amount,
        MAX(fraud.timestamp, withdraw.timestamp) as
timestamp, 'withdrawlFraud' as desc
from FraudWarningEvent.win:time(60 min) as fraud,
        WithdrawalEvent.win:time(60 sec) as withdraw
where fraud.accountNumber = withdraw.accountNumber
```

Listing 3. EPL example joins 2 event streams [53.]

3 Implementation of ETSIVÄ Building Energy Data Inspector tool

This chapter presents the ETSIVÄ Building Energy Data Inspector tool that was developed during this research project. The tool is based on the literature study done at the beginning of the research. The recommendations from the literature study regarding what constitutes a good FDD tool were taken into account in the design. The chapter begins with a description of the system architecture. This is followed by the ETSIVÄ visualisation chapter, which introduces the tool's visualisations in stages.

3.1 System architecture

The ETSIVÄ tool architecture contains the building automation system of the building of the Kontula Residential Care Home -building and a network server at the City of Helsinki Public Works Department (HKR) and a server at VTT. The system uses the building automation system of Kontula Residential Care Home to collect the necessary data. The collected data consists of three different metric calculations: ten-minute interval data, one-hour interval data, and one-day interval data. These three interval data sets are passed from the Kontula Residential Care Home -building to the HKR server. Data transfer between the HKR and VTT servers is via a secured Virtual Private Network (VPN) on the Internet. Data files are transferred automatically once a day by using the VPN -tunnel from the HKR server to the server at VTT. In addition, the data files are converted into a database in the server. Different kinds of visualisations are created with the ETSIVÄ tool for the user in the web browser. The architecture of the system is presented in figure 8.

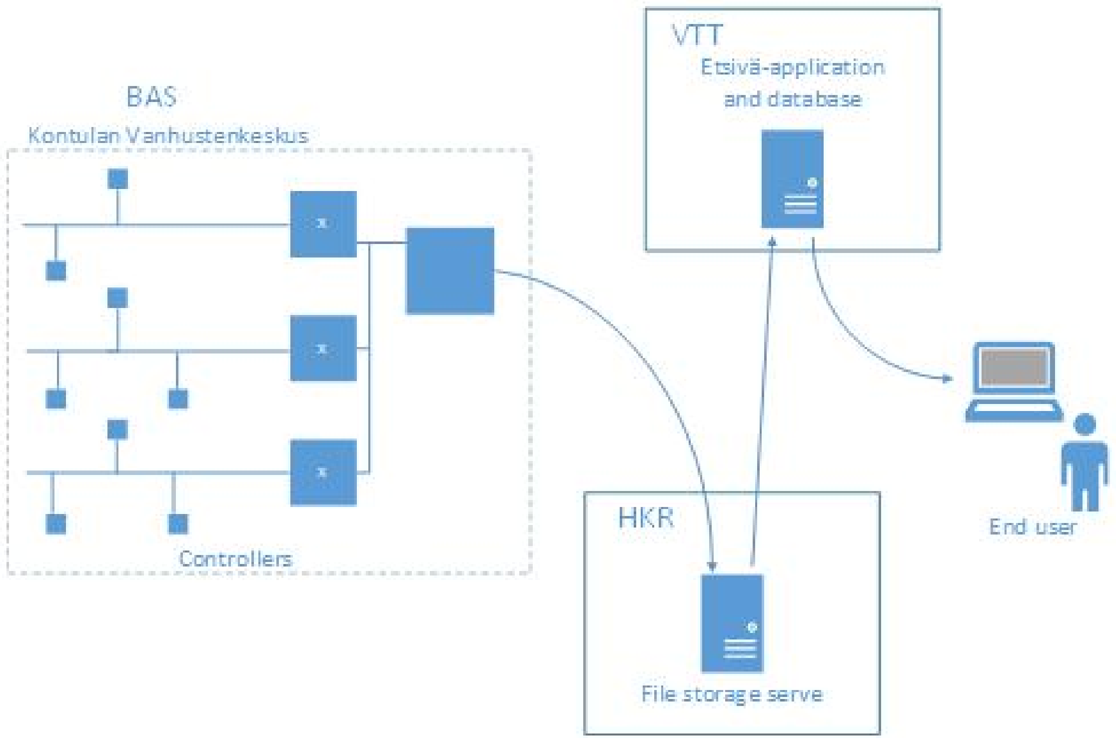

Figure 8. Architecture of the ETSIVÄ Building Energy Data Inspector tool

Application visualization graphs are mainly done with WebFOCUS, a third-party application. WebFOCUS offers an easy way to create reports with large scalability. It suits well to an end user with large-scale applications, as well as to power users who want to have access to raw data. With WebFOCUS the users can easily create their own reports and analyses from the data. The system framework is programmed using the Hypertext Preprocessor (PHP) scripting language, HTML (HyperText Markup Language), and JavaScript programming languages. PHP is a general scripting language that is particularly suitable for web development and it can be easily embedded in the HTML scripting language.

The performance metrics of the ETSIVÄ tool can be accessed with common web browsers. To sign in to the system and access the ETSIVÄ tool via a web browser, an internet connection, a username, and a password are required.

3.2 Transforming building automation data into performance metrics

Building automation data is transformed into performance metrics by comparing measured values to expected values. The performance metric can include one or two values: for example, heat recovery efficiency has one target value (e.g. 80%) and indoor temperature has two values (e.g. 20–26 °C).

The front page of the ETSIVÄ tool gives a comprehensive overview of the building at a glance. Building performance is defined on the front page by four meters that show the current situation of the building (figure 9). The four meters on the front page measure energy efficiency, indoor climate, functionality, and alarms.

Buildings are listed in the menu on the right in a list and every building is rated accoding to traffic signal lights. Green indicates that everything is very well, yellow indicates that everything is well, and red indicates that there is something wrong in the building. Users can see the situation of each building.

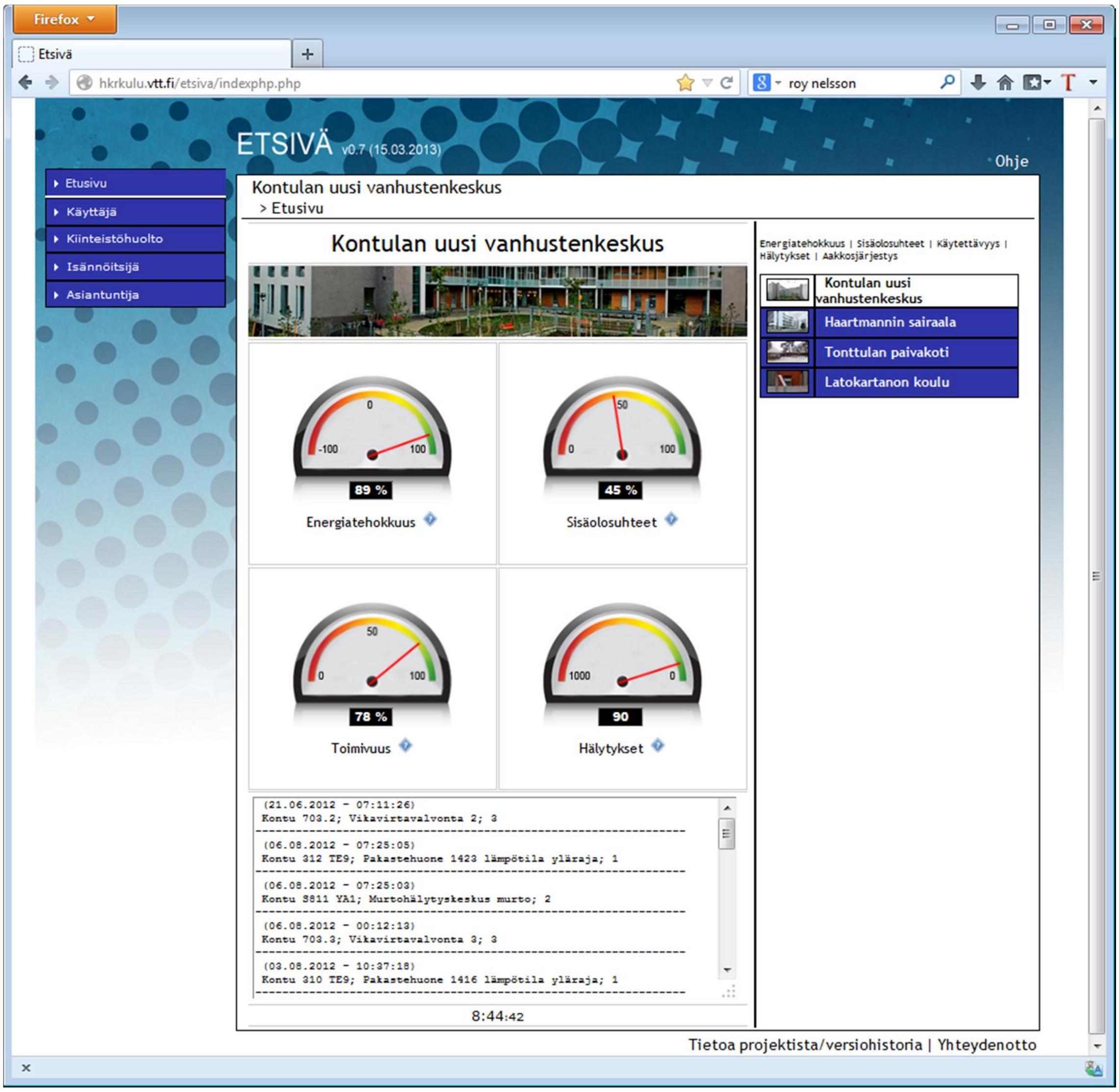

Figure 9. Front page of the ETSIVÄ Building Energy Data Inspector tool

The first meter at the top left side gives a reading for energy efficiency that is calculated on the basis of the comparative values of the previous seven days. The comparison is calculated based on electricity and water consumption. The second meter at the top right side gives a reading for indoor climate. The indoor climate comparative value is based on the indoor temperatures and air quality (CO_2) stability for the previous seven days, averaged according to the indoor climate classification limits. The third meter at the bottom left side gives a reading for functionality. The comparative value in the functionality meter is the building ventilation units' running times within the previous seven days compared to the City of Helsinki low-energy guidance. A low-energy guidance is set according to the typical ventilation unit running time. The fourth meter at the bottom right side depicts Alarms and shows any recorded alarms within the building’s automation system in the last seven days.

The ETSIVÄ tool also offers drill down capabilities to access detailed information behind each metric (see figure 10). The ETSIVÄ tool was created using good practices found in studies already described in Chapter 2.4.

In addition to the front page, the ETSIVÄ tool includes a menu on the left side of the user interface (UI). By using a menu, the user can drill down to more detailed and specific information. The menu offers different options to different user groups: a basic user has access to only basic information; property maintenance staff and the property manager have access to more information and the expert group have access to all the information.

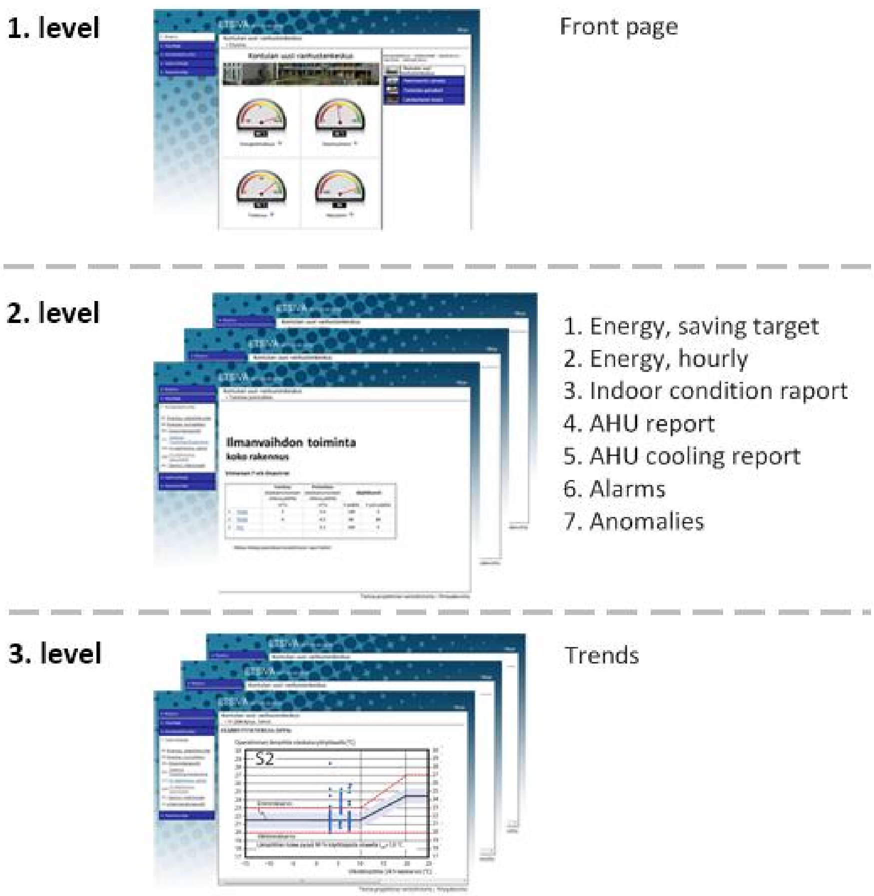

Figure 10. ETSIVÄ -application reporting hierarchy is shown

On the second level of reporting, the basic user can see energy reports. Energy saving reports include an energy saving target report and an hourly energy consumption report. The energy saving target report shows a comparison between the energy used and the target that was set. The hourly energy consumption report shows an hourly energy consumption time series.

Property maintenance staff can see the same reports as the basic user above. In addition, property maintenance can see the condition report, the HVAC-air report, the HVAC-cooling report, the HVAC-cooling running times report, and the alarms report. The HVAC-air report shows the air flows of the AHU. The HVAC cooling power report shows the cooling power. The running time report for HVAC shows the AHU running times, and finally the alarms report shows the alarms. Property maintenance staff can view, for example the cooling energy (as seen in figure 11).

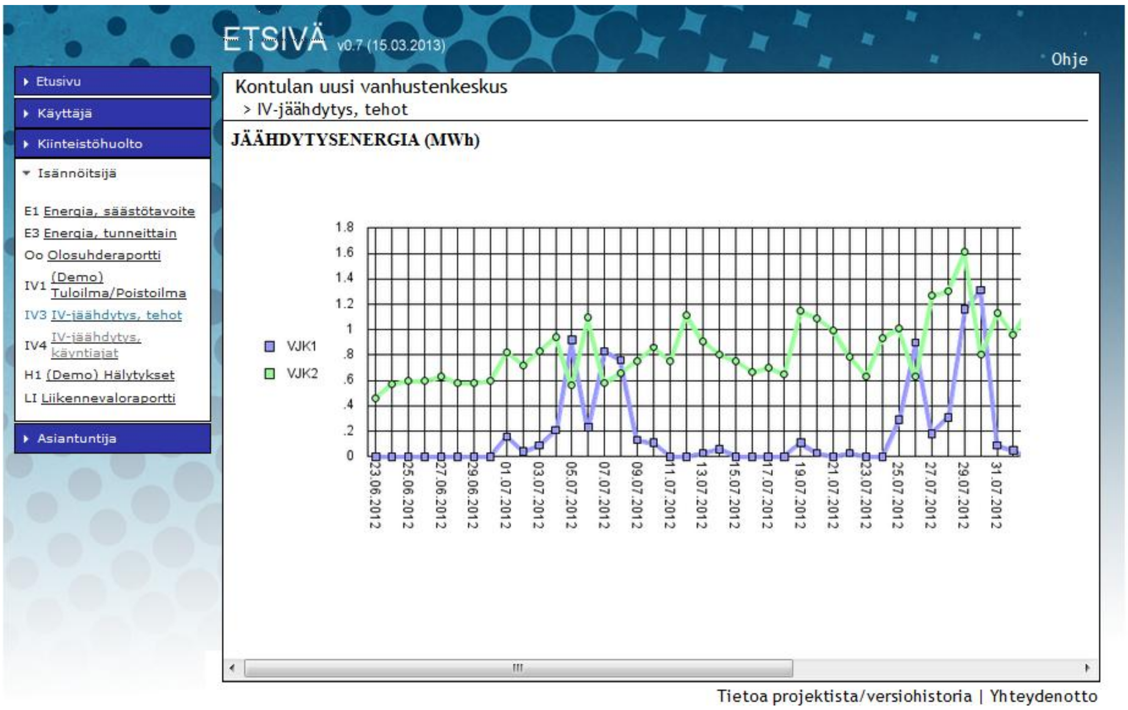

Figure 11. Example of the ETSIVÄ application diagram. Trend graph of the building's cooling energy.

A building manager can see the same reports as the basic user and the property maintenance staff, as described above. In addition to these, the building manager can see the traffic light report, which shows the anomalies of the AHUs.

An expert can see the same reports as a basic user, property maintenance staff, and building manager, as described above. In addition, the expert can see a distribution report, the maximum values report, and the standard deviation and variance reports.

The ETSIVÄ application produces an interesting graph about the inside temperatures of rooms. The graph places the daily values of indoor temperatures in the graph according to the Finnish indoor climate class. In this particular case, the indoor climate class is S2 so the application draws the daily indoor air temperature of a certain room as blue balls to the graph. The X-axis of the graph describes the outdoor temperature and the Y-axis of the graph describes the indoor air temperature and the blue dots describe how the indoor air of the room behaves. A more detailed graph is presented in figure 12.

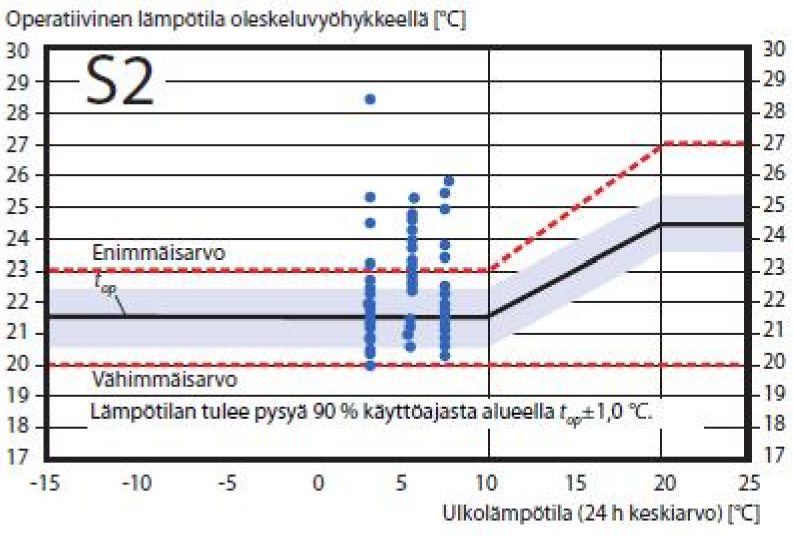

Figure 12. ETSIVÄ application report: indoor temperature stability diagram. Blue spots are hourly values of the chosen room.

4 Implementation of Complex Event Processing

Implementing the complex event processing (CEP) method begins by choosing the appropriate CEP engine. The development environment and debugging of CEP are introduced, and finally the test case and test are analysed in more depth.

4.1 Complex Event Processing engine Esper / NEsper

Esper is an open source component for complex event processing (CEP) and available for Java language as Esper and for Windows .NET environment as NEsper. Esper and NEsper components are written in C# and Java coding languages. Both components can run in standalone mode. Esper can detect different kinds of complex event patterns. In addition, Esper also has its own Event Processing Language (EPL). The Enterprise Edition is a commercial version of NEsper and has more advanced features, with the possibility to obtain support and high availability features [56].

Almost any kind of a CEP engine could have been chosen for this study, but Esper/Nesper was selected. It is open source and it is Windows compatible. Unfortunately, Esper lacks a graphical user interface (GUI), but that was not thought to present any problems for this research project.

4.2 Test case - Air Handling Unit (AHU) deviation

The Complex event processing (CEP) research case is an Air Handling Unit (AHU) deviation. Once the AHU set temperature changed, the CEP method monitors whether the temperature actually changes fast enough to the selected temperature range. The purpose of the AHU is to produce air which corresponds with the adjusted set value.

The requirements that need to be taken into account, whether the temperature actually changes fast enough to the selected temperature range, are listed here:

1. The algorithm should identify when the AHU set temperature value changes.

2. The algorithm should identify whether the difference between the set temperature and the measured temperature is more than 1 °C of the set temperature 10 minutes after the set temperature value is changed.

4.3 Development and testing environment

All development was done in the Microsoft Windows environment. The CEP system was implemented using the following tools NetBeans IDE 7.2.1 (Build 201210100934) was used as an Integrated Development Environment (IDE) for the Java framework and Event Processing Language (EPL) coding and editing, framework coding language in NetBeans is Java 1.7.0_10; Java HotSpot(TM) 64-Bit Server VM 23.6-b04, the Complex Event Processing Engine used is Esper 4.7.0

Development and testing was performed on a Hewlett-Packard EliteBook 8560p laptop, with the following specifications: Microsoft Windows 7 Enterprise 64-bit operating system; Service Pack 1, Intel Core i7-2620M CPU @ 2.70GHz, 8GB memory, 300GB hard drive

The test data is from the Kontula Residential Care Home building and the data format is a CSV file. The CSV file contains timestamp (time), tset (time set), tmeasured (time measured) and outside temp (outside temperature) value separated with commas.

The statements of the event processing application are written in an external editor or directly within the development environment as a string in the Java code. Since Esper does not have its own development environment, it lacks many helpful features that modern development environments have. Features that would be very helpful include an auto completing event and function names, syntax highlighting, code refactoring helpers, and integrated help for the event processing language.

4.4 Debugging

Debugging is an important tool in the implementation phase and it usually speeds up solving coding errors. Traditionally, debugging means that the developer of the code can run the software and halt its execution at some point to examine the variables and execute the code row by row to see what the software does. In traditional languages, debugging is a part of software development.

Another way to see what the program is doing is to add logging to the code. The program can write information to a log file or on the screen about the parameters it is using at the time. In error situations, it is easier to find the errors from the log files.

In the Complex Event Processing engine, debugging is not as smooth as in the integrated development environment. The statements cannot be printed out to any log file and neither can stop statement execution at any point to follow which events are executed. If the debug log is enabled in the CEP engine, lots of debugging logs are printed out. The debug log tells what it is doing and that can sometimes be useful when statements are not working as they should be. However, a better way is to add own specific statements to the listener and print them on the screen. When the statement outputs the events, they can easily be debugged.

4.5 Implementation of the Air Handling Unit (AHU) deviation test case

The test case presented in section 4.2 is implemented using the Esper Event Processing Language (EPL), with the help of a test framework made in Java language. The implementation is documented here with all the Event Processing Language codes.

The Air Handling Unit (AHU) deviation algorithm implementation started with the design phase, by establishing how the algorithm should work to satisfy the requirements set for the test case. The basic functionality is rather simple and the algorithm works with one statement. While implementing this algorithm, it became obvious that there is also a need to identify any deviations if the temperature is decreasing too slowly.

Air Handling Unit (AHU) deviation algorithms are presented below. The Event Processing language (EPL) statement is illustrated in listing 1 above.

```
1 select * from TemperatureEvent match_recognize
2         (measures A as tset, B as tset2, C as tset3
3         pattern
4         (A B C)
5         define
6         B as (B.tset > A.tset and B.tmeasured < (B.tset -
100)) or (B.tset < A.tset and B.tmeasured > (B.tset +
100)),
7         C as (C.tset > A.tset and C.tmeasured < (C.tset -
100)) or (C.tset < A.tset and C.tmeasured > (C.tset + 100))
)
```

Listing 4. Air Handling Unit (AHU) deviation algorithm

In plain text, the code in listing 4. above means:

Line 1: All columns from data stream are selected

Line 2-4: Creates pattern of the three last values: A, B and C

Line 6: Checks that the measured temperatures are ±1 °C from set temperatures. If they are not, whole event is rejected.

Line 7: Checks that the measured temperatures are ±1 °C from the set temperatures and if they are, an event is found and reported.

4.6 Tests

The Air Handling Unit (AHU) deviation EPL algorithm is tested in this paragraph. The research question is to find the same deviation that the ETSIVÄ Building Energy Data Inspector tool found. The CEP functionality can be tested by choosing one deviation that the ETSIVÄ Building Energy Data Inspector tool found and use the same data with the CEP. Figure 13 below is from the ETSIVÄ Building Energy Data Inspector tool. The AHU is not working properly. It increases the room temperature too slowly. The ETSIVÄ fault detection and diagnostic tool shows these deviations with red spots. The black line is the set temperature, the green line is the measured temperature and the blue line is the outside temperature. The data are from the Kontula Residential Care Home, the AHU identification code is YIT_KontulaUVK_204TK_TE5. The time range for the time series was observed 15–16 September 2012. The data is taken at 10-minute intervals, so that every 10 minutes the temperatures are logged in the file. The rule which searched for is whether 10 minutes after a set temperature adjustment is made, the measured temperature is between ±1 °C of the set temperature. Otherwise the AHU is not working properly.

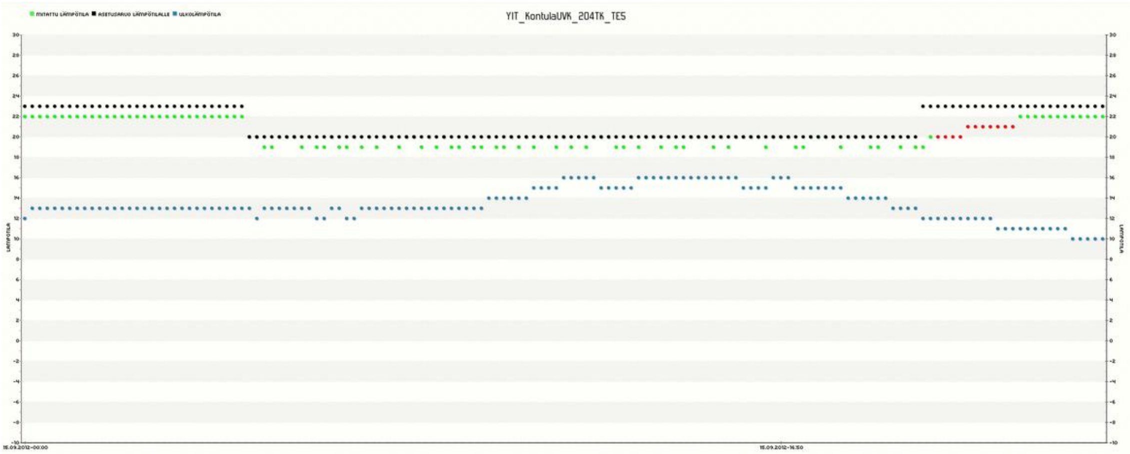

Figure 13. Deviation found from the ETSIVÄ Building Energy Data Inspector tool.

Esper is tested with the CVS file that contains building data for the Kontula Residential Care Home for one whole day. Actually, Esper could be set to listen for real-time data stream from the AHU. The data do not have to be stored in the database first. Esper can listen to the data stream and the data can be destroyed after Esper has evaluated the data. In the test, Esper listened to the CSV file, which contained historical values. The test case events were printed on the screen one event at the time and Esper was able to find the defined complex event from the data stream. In real life Esper could listen to the data stream and send the complex events that it finds to the building control system, by email or by SMS, for example. Figure 14 below is a complex event that the EPL statement found from the data stream.

```
Event [temperature_set=20.00, temperature_measured=19.95, time=2012-09-15-19-00-00]
Event [temperature_set=20.00, temperature_measured=20.00, time=2012-09-15-19-10-00]
Event [temperature_set=20.00, temperature_measured=20.02, time=2012-09-15-19-20-00]
Event [temperature_set=20.00, temperature_measured=19.97, time=2012-09-15-19-30-00]
Event [temperature_set=20.00, temperature_measured=20.03, time=2012-09-15-19-40-00]
Event [temperature_set=20.00, temperature_measured=19.95, time=2012-09-15-19-50-00]
Event [temperature_set=23.00, temperature_measured=19.97, time=2012-09-15-20-00-00]
Event [temperature_set=23.00, temperature_measured=20.13, time=2012-09-15-20-10-00]
Event [temperature_set=23.00, temperature_measured=20.38, time=2012-09-15-20-20-00]
*******************************************************************************
* [ALERT] : CRITICAL EVENT DETECTED : Measured temperature adjust too slow!     *
* temperature_set=23.00, three last measured temperatures [19.97, 20.13, 20.38]  *
*******************************************************************************
Event [temperature_set=23.00, temperature_measured=20.53, time=2012-09-15-20-30-00]
Event [temperature_set=23.00, temperature_measured=20.70, time=2012-09-15-20-40-00]
Event [temperature_set=23.00, temperature_measured=20.95, time=2012-09-15-20-50-00]
Event [temperature_set=23.00, temperature_measured=21.17, time=2012-09-15-21-00-00]
Event [temperature_set=23.00, temperature_measured=21.37, time=2012-09-15-21-10-00]
Event [temperature_set=23.00, temperature_measured=21.48, time=2012-09-15-21-20-00]
Event [temperature_set=23.00, temperature_measured=21.57, time=2012-09-15-21-30-00]
Event [temperature_set=23.00, temperature_measured=21.70, time=2012-09-15-21-40-00]
Event [temperature_set=23.00, temperature_measured=21.90, time=2012-09-15-21-50-00]
Event [temperature_set=23.00, temperature_measured=21.90, time=2012-09-15-22-00-00]
Event [temperature_set=23.00, temperature_measured=22.00, time=2012-09-15-22-10-00]
Event [temperature_set=23.00, temperature_measured=22.10, time=2012-09-15-22-20-00]
```

Figure 14. Esper detected a complex event from the data stream. The AHU was not working properly.

It was possible to perceive the faulty function of the AHU also by using CEP. There were no references in the literature that CEP could be used to analyse building automation data before, so the result is significant.

5 Experiences with the implementations

Several observations were made during the study. First, the findings of the application development stage are presented, then the complex event program implementation is demostrated.

5.1 Experience with the ETSIVÄ Building Energy Data Inspector software implementation

Everyone from the building user to top management can use the ETSIVÄ Building Energy Data Inspector tool to track the current performance of buildings, based on the static scale from red to green in the metres. Technical personnel can use the system to find reasons for degraded performance. Less technical users can use the system to observe the actual performance of the building. The ETSIVÄ performance metrics can also be included in the maintenance contracts of the building. In this way, the ETSIVÄ Building Energy Data Inspector tool could be used to measure how well the performance requirements are met in the building.

Besides ETSIVÄ being used as a management tool, it can also be used fo building performance monitoring. The ETSIVÄ tool increases the building operation optimisation, improves the quality of the indoor environment and leads to lower energy costs. By using the ETSIVÄ tool, it is possible to obtain timely information from a building. All the information is taken from a single system, in an easily readable format. From the front page of the web application, the user gets a good overall impression of the building. The user can use the drill down option to obtain a detailed performance report. With the detailed reporting of the building, the ETSIVÄ tool makes it possible to see historical trends. Automatic fault correction is not included in the ETSIVÄ application. Fault perception remains the responsibility of users.

By using the ETSIVÄ tool, the building problems can be identified before they start to create problems in the indoor environment, and before complaints emerge from the users of the buliding or before the building energy costs have increased signficantly. For example, in S1 and S2, operative temperature target values with metric forms can be used to detect the discomfort of users.

By using the ETSIVÄ Building Energy Data Inspector tool, can be detected many different kinds of performance anomalies and faults. For example, the following problems could be detected:

- From the traffic-light report it is possible to detect that the AHU is not reaching the set temperature quickly enough, as seen in figure 15.
- From the ETSIVÄ tool too cold or warm areas can be detected
- From the ETSIVÄ tool it is possible to detect broken sensors
- From the ETSIVÄ tool unnecessary AHU operations can be detected.

The AHU in figure 15 is not working properly. It increases the temperature too slowly. The ETSIVÄ Building Energy Data Inspector tool shows these deviations in red dots. Black depicts the set temperature, green depicts the measured temperature and blue depicts the outside temperature.

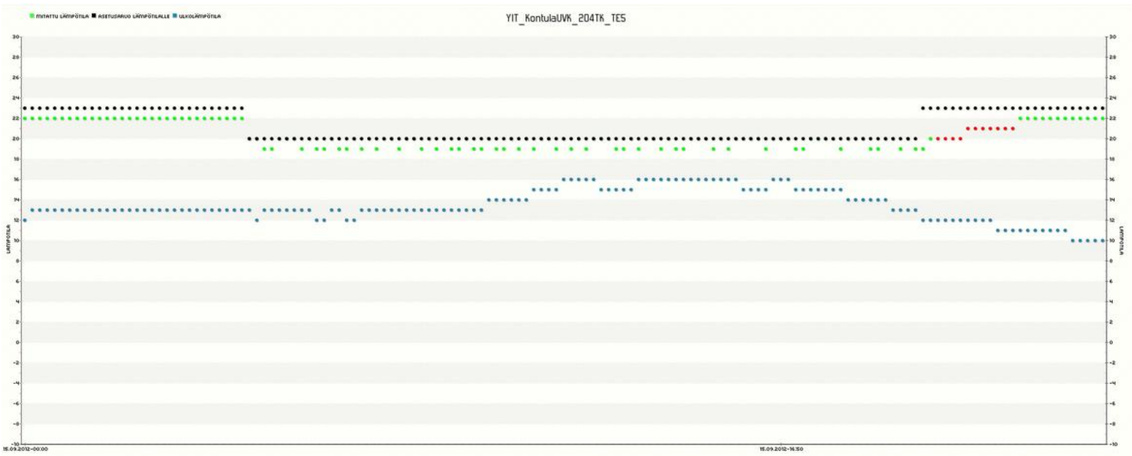

Figure 15. Deviation found from the ETSIVÄ Building Energy Data Inspector tool.

The ETSIVÄ Building Energy Data Inspector tool displays three performance metrics in a percentage format. The percentage formats are achieved by comparing the measurements with pre-determined targets. Target values can be derived, for example, from building standards or from guides. Presenting the information as relative figures has both advantages and disadvantages. Relative figures offer an opportunity to manipulate the information consciously or unconsciously. As a result, it is essential to know which figures are compared to others. On the other hand, a relative presentation makes the information easier to understand for a person with no background information in the subject. For example, the indoor performance metric could give good values if compared to the S3 requirements, but poor values if compared to the S1 requirements.

5.2 Experience with the Complex Event Processing case implementation

Used Air Handling Unit (AHU) deviation –statement is illustrated in listing 5. This simple statement below finds an event if the deviation is ± 1°C after ten minutes of the AHU having changed its set temperature setting. Finding the same deviations from the ETSIVÄ Building Energy Data Inspector tool requires a human with some expertise who can look at the charts and find the point at which the AHU is seen to be not working properly from the huge amount of data. First, data have to be put into the database and from the database, deviations can be searched for by using the ETSIVÄ tool. Instead of using the CEP one can find these deviation patterns instantly from the live data stream, with minimal code, and then automatically inform the necessary persons about any deviations found.

```
select * from TemperatureEvent match_recognize
         (measures A as tset, B as tset2, C as tset3
         pattern
         (A B C)
         define
         B as (B.tset > A.tset and B.tmeasured < (B.tset -
100)) or (B.tset < A.tset and B.tmeasured > (B.tset +
100)),
         C as (C.tset > A.tset and C.tmeasured < (C.tset -
100)) or (C.tset < A.tset and C.tmeasured > (C.tset + 100))
)
```

Listing 5. Air Handling Unit (AHU) deviation -statement

The plan was to test how CEP can be used to analyse the AHU data with at least three different test cases, but unfortunately a lack of time prevented any further test cases.

6 Results

This thesis had three objectives: First, to create the ETSIVÄ Building Energy Data Inspector demonstration tool for the use of City of Helsinki Public Works Department. The second objective, research question one, was to establish whether building automation data from the City of Helsinki Public Works Department could be visualised to find important information and anomalies, which could in turn lead to energy savings and increased functionality of the building. The third objective was to study whether the anomalies identified with the ETSIVÄ application to answer the first research question can also be found with the Complex Event Processing (CEP) method. CEP can provide faster and easier approaches to analysing whole-building data quickly and also in real time.

The main objective of this thesis was to create the Building Energy Data Inspector demonstration tool ETSIVÄ for the use of City of Helsinki Public Works Department. It was possible to complete the ETSIVÄ Building Energy Data Inspector demonstration tool within the time frame of this project. However, not all the planned functionalities, especially the more advanced functionalities, could be implemented in the project, due to time constraints. The ETSIVÄ Building Energy Data Inspector tool visualises building automation data in a manner that is easy to understand. The system creates an overview of every building on the front page of the browser based application, allowing the user to monitor the situation of all buildings at a glance. The system offers information that is sufficiently detailed to allow the user to access the real problems of the building.

Since several countries have set ambitious targets for energy efficiency and the reduction of greenhouse gas emissions, it is inevitable that the energy use of buildings has got to be reduced as part of achieving end-use efficiencies. To reach these goals of low and zero energy buildings, innovative technology and building design is needed. At the same time, it is important that energy efficiency is not achieved at the cost of the quality of the indoor environment. One way to address the problem is to use advanced tools like the ETSIVÄ Building Energy Data Inspector tool.

The research questions presented in Chapter 1 are answered below:

1) Can the ETSIVÄ Building Energy Data Inspector tool visualise building automation data and find anomalies that can save energy and increase the functionality of the building?

There were some technical difficulties during this research project, for example, in creating the VPN tunnel between VTT and the City of Helsinki Public Works Department. The ETSIVÄ Building Energy Data Inspector tool could only analyse a single building, the Kontula Residential Care Home building. However, something interesting was found in the Kontula Residential Care Home building data. It was identified that the AHU did not work properly and that the case coule be analysed by means of the CEP. In summary, one can say that the project succeeded in visualising the Kontula Residential Care Home building automation data for the City of Helsinki Public Works Department. Furthermore, anomalies that when addressed could save energy and increase the functionality of the building were found.

2) Can the anomalies found by the ETSIVÄ Building Energy Data Inspector tool also be found with CEP?

The Complex Event Processing research carried out in this thesis states that CEP could, theoretically, be used to find the same deviation as the ETSIVÄ Building Energy Data Inspector tool had found. However, because of lack of time, a study of more interesting deviations was not possible. There was only little time to test the one deviation found with the ETSIVÄ Building Energy Data Inspector tool. CEP is still a relatively new technology, still evolving and establishing itself, especially in the building sector. During the literature review, it appeared that CEP had not been used to analyse building automation data previously. However, CEP is a very promising technology, especially in the future when the Internet of buildings and smart grids increase CEP scalability to the new areas. Furthermore, data streams will increase in the future and there will be a greater need to analyse data in real time.

7 Further study

The ETSIVÄ Building Energy Data Inspector tool was constructed as part of this master's thesis project. However, there are many interesting ways how the software could be developed further. In this respect, here are some suggestions for this future work:

- The more advanced expert views could be improved.
- Big data tools could be used to analyse data from the entire building stock of the Helsinki city.
- Predictive analytics could be used to analyse building data, which could improve building functionality, indoor air quality, and energy efficiency.

8 References

1 VTT Technical Research Centre of Finland. (2007). Energy Use. Visions and Technology Opportunities in Finland, VTT Edita. Helsinki; 2007

2 International Energy Agency. World Energy Outlook [online]. URL: http://www.iea.org/publications/scenariosandprojections/. Accessed 17 October 2015.

3 European Commission [online]. EU’s energy related strategies. European Comission. URL:https://ec.europa.eu/energy/en/topics/energy-strategy/2020-energy-strategy. Accessed 17 October 2015

4 Säteri J. Buildings and environmental change in Finland. Power Point slide; 2013.

5 Mahdavi A. User control actions in buildings: Patterns and impact. Proceedings of Clima 2007 Well Being Indoors. Vienna University of Technology, Austria; 2007.

6 Houttu J. Facility technical metrics – industrial maintenance methods and solutions applied to facility maintenance. Master’s Thesis. TKK. Espoo; 2008.

7 Pietiläinen J., Kauppinen T., Kovanen K., Nykänen V., Nyman M., Paiho S., Peltonen J., Pihala H., Kalema T., Keränen H. The building commissioning procedure in Finland (ToVa). VTT Tiedotteita 2413. VTT. Espoo; 2007.

8 Rakennustietosäätiö. Classification of indoor environment 2008 Target Values, Design Guidance, and Product Requirements; 2009.

9 Seppänen O. Ilmastointitekniikka ja sisäilmasto. Suomen LVI-yhdistysten liitto. Espoo; 1996.

10 Kautto J. Rakennuksen automaatio- ja energiainformaatiojärjestelmät ja tarpeenmukainen käyttö. Master’s Thesis. Aalto University; 2012.

11 BAFF (Building Automation Forum in Finland) [online]. Rakennusautomaatiolla saavutettavissa olevat hyödyt. Suomen Automaatioseura ry. URL:http://www.automaatioseura.fi/index/tiedostot/BAFF_%20hyodyt.pdf. Accessed 17 October 2015.

12 Månsson L-G., McIntyre D. Technical Synthesis Report. A Summary of IEA Annexes 16 & 17 Building Energy Management Systems. International Energy Agency, Energy Conservation in Buildings and Community Systems; 1997.

13 Wacklin J. Taajuusmuuttajan mittaustiedon hyödyntäminen kiinteistöteknisissä käytöissä. Master’s Thesis. Tampere; 2009.

14 Ihasalo H. Transforming building automation data into building performance metrics- design, implementation of use of a performance monitoring and

management system. Doctoral dissertation. Aalto University. School of Electrical Engineering. Department of Automation and Systems Technology. Espoo; 2012.

15 Katipamula S., Pratt R., Chassin D. P., Taylor Z. T., Gowri K., Brambley M. Automated fault detection and diagnostics for outdoor-air ventilation systems and economizers: Methodology and results from field testing. ASHRAE Transactions. Vol.105. No. 1; 1999.

16 Friedman H., Piette M. Comparative Guide to Emerging Diagnostic Tools for Large Commercial HVAC Systems. Lawrence Berkeley National Laboratory Report 48629; 2001.

17 Schein J., Bushby S. T. Fault Detection & Diagnostics For AHUs and VAV Boxes. AHRAE Journal 47.7; 2005.

18 Hyvärinen J., Kärki S. Building Optimization and Fault Diagnosis Source Book; IEA Annex 25. Technical Research Centre of Finland. Espoo; 1996.

19 Isermann R. Fault-Diagnosis Systems: An Introduction from Fault Detection to Fault Tolerance. New York. Springer. 493 p. ISBN 3-540-24112-4; 2005.

21 Brambley M., R. Pratt R. G. Using Automated Diagnostic Tools to Provide energy Services. Proceedings of the ACEEE 2000 Summer Study on Energy Efficiency in Buildings. Washington D.C; 2000.

22 Katipamula S. M., Brambley R., Bauman N., Pratt R. G. Enhancing building operations through automated diagnostics: Field test results. Proceedings of 2003 International Conference for Enhanced Building Operations. Berkeley, CA; 2003.

23 Braun J., Li H. Automated fault detection and diagnostics of rooftop air conditioners for California. Deliverables 2.16a &2.1.6b; 2003.

24 Katipamula S., Brambley M. Methods for Fault Detection, Diagnostics, and Prognostics for building Systems - A Review, Part I. International Journal of HVAC&R Research; 2005.

25 Katipamula S., Brambley M. Methods for Fault Detection, Diagnostics, and Prognostics for building Systems – A Review, Part II. International Journal of HVAC&R Research; 2005.

26 Hirvonen J., Venttä O. Desing Process for Intelligent Algorithm Intensive Systems The 2nd International Multi-Conference on Engineering and Technological Innovation, Proceeding Volume I. International Institute of Informatics and Systemics; 2009.

27 Smith W. Final Report: Energy efficient and affordable commercial and residential buildings. California Energy Commission: Berkeley, CA, USA; 2003.

28 Motegi N., Piette M., Kinney S., Herter K. Web-based Energy Information Systems for Energy Management and Demand Response in Commercial Buildings. Lawrence Berkley National Laboratory. LBNL-52510; 2002.

29 Brown K., Anderson M., Harris J. How Monitoring-Based Commissioning Contributes to Energy Efficiency for Commercial Buildings. Proceedings of the 2006 ACEEE Summer Study on Energy Efficiency in Buildings. Vol. 3; 2006.

30 Granderson J., Piette M., Ghatikar M. A., Price G. Building Energy Information Systems: State of Technology and User Case Studies. Lawrence Berkley National Laboratory. LBNL-2899E; 2009.

31 Few S. Information dashboard design: The effective visual communication of data. Sebastopol, CA, USA. O'Reilly Media; 2006.

32 VTT symposium 217. Demostrating Automed Fault Detection and Diagnosis Methods in Real Buildings. ANNEX 34. VTT Technical research Centre of Finland. Espoo; 2001.

33 Smith S., Mosier J. Guidelines for designing user interface software. The MITRE Corporation Bedford, Massachusetts, USA; 1986.

34 Karjalainen S. Consumer preferences for feedback on household electricity consumption. Energy and Buildings 43. 2011. Elsevier Science Ltd; 2010.

37 Lehrer D., Vasudev J. Visualizing Information to Improve Building Performance: A Study of Expert Users. Proceedings of the ACEEE Summer Study on Energy Efficiency in Buildings. Pacific Grove, CA, August 15-20; 2010.

38 Marini K., Ghatikar G., Diamond R. Using Dashboard to Improve Energy and Comfort in Federal Buildings. Lawrence Berkley National Laboratory.LBNL-4283E; 2011.

39 Pitcher J., Watson R. (2012). Guest Post: The Energy Dashboard Delusion. URL:http://www.greentechmedia.com. Accessed 17 October 2015.

40 Vassileva I., Odlare M., Wallin F., Dahlquist E. Impact of consumers feedback preferences. Applied Energy 93. Elsevier Science Ltd; 2011.

41 Karjalainen S., Piira K. Improving the possibilities to monitoring energy consumption at home. VTT. Espoo; 2007.

42 Simon H. Theories of decision-making in economics and behavioural science. The American Economic Review; 1959.

43 Ek K., Söderholm P. The devil is in the details: Household electricity saving behaviour and the role of information. Energy Policy 38. Elsevier Science Ltd; 2009.

44 Karjalainen S., Koistinen O. User problems with individual temperature control in offices. Building and Environment 42. 2007. Elsevier Science Ltd; 2005

45 Valli M. Käytettävyys odottaa edelläkävijää. Talotekniikka 3/2012; 2012.

46 EU project EEPOS. (2012-2015). EEPOS End-User Collaboration Tool Specification Report.

URL:http://eepos-project.eu/wp-content/uploads/2013/10/eepos-performance-monitoring-and-operational-planning-tools.pdf. Accessed 17 October 2015.

47 Lucid Building Dashboard [online]. URL:http://luciddesigngroup.com/buildingdashboard/web.html. Accessed 17 October 2015.

48 BuildingIQ [online]. URL:http://www.buildingiq.com. Accessed 17 October 2015

49 Zimmerman M. The Next Generation of Building Energy Efficiency [online]. October 2011. URL:http://www.automatedbuildings.com/news/oct11/articles/buildingiq/111001103707buildingiq.html. Accessed 17 October 2015

50 Lindström J. Algorithmic Trading and Complex Event Processing. Master's Thesis. Aalto University. Espoo; 2010.

51 Lucham D. The Power of Events. An Introduction to Complex Event Processing in Distributed Enterprise Systems. Addisson-Wesley; 2002.

52 Complex Event Processing with Esper [online]. URL:http://coffeeonesugar.wordpress.com/2009/07/19/complex-event-processing-with-esper/. Accessed 17 October 2015

53 Complex Event Processing [online]. URL:http://esper.codehaus.org/tutorials/tutorial/tutorial.html. Accessed 17 October 2015

54 Darby S. The Effectivenexx of Feedback on Energy Consumption: A Review for DEFRA of the Literature on Metering, Billing and Direct Display. Environment Change Institute, University of Oxford; 2006.

55 Software AG University Relations [online]. URL:http://techcommunity.softwareag.com/ecosystem/communities/public/universities/SAEP/Introduction/events-and-event-processing/. Accessed 17 October 2015

56 Esper [online]. URL:http://esper.codehaus.org/. Accessed 17 October 2015