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Monitoring Based Commissioning Activities in LEED Certification Process

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Bachelor of Engineering

Sustainable Building Engineering

Thesis

7 February 2018

Metropolia

Author Title Number of Pages Date	Viktoria Nadas Monitoring Based Commissioning Activities in LEED Certification Process 41 pages 7 February 2018
Degree	Bachelor of Engineering
Degree Programme	Civil Engineering
Professional Major	Sustainable Building Engineering
Instructors	Pekka Mairinoja, CEO Lauri Heikkinen, Principal Lecturer

The purpose of this thesis was to suggest a functional procurement plan for Monitoring Based Commissioning, within the framework of LEED certification. The procurement is applied to Finnish climate and statutes. The approach of the thesis was to provide a deep yet practical understanding of this LEED-specific procurement process.

To achieve this purpose, extensive literature research, interviews and a case study were conducted. The research included academic papers from various fields, such as energy efficiency, energy management, facility management, building automation, building modeling and simulation, European Union and Finnish legislation. Apart from the literature research, the author has conducted interviews with several colleagues and utilized internal documents of the company. Additionally, a case study was applied, to test the actual functionality of Monitoring Based Commissioning.

The result of the was a plan that summarizes the focus points of procurement prior to project preparation. They were disseminated within the company in order to get the employees familiar with this type of commissioning and utilize the gained knowledge in future procurement. The thesis also suggests further fields and subject to continue investigating.

Keywords	building automation, energy management, maintenance

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Contents

Acknowledgement

This Bachelor thesis is the result of a long journey and constant learning. Also, my first step towards fulfilling my dreams to take a responsible part in the technical development of my environment as an engineer. This work is based on my interest and desire to explore more about the mostly hiding systems working around us.

I am greatly thankful to my teachers for the education they provided, to my instructor for having the trust in me, to my colleagues for the patient training sessions and endless explanations, to my friends for standing by me and to my family for encouraging me to pursue my goals.

List of Abbreviations

LEED v4	Leadership in Energy and Environmental Design, version 4
FBC	Finnish Building Code
MBCx	Monitoring Based Commissioning
Cx	Commissioning Process
BAS	Building Automation System
BMS	Building Management System
EMS	Energy Management System
DDC	Direct Digital Control
DAQ	Data Acquisition System

1 Introduction

1.1. Background and Motivation

Sustainability and sustainable development is a prevalent concept emerging from the 1980s. Since 1983 when the United Nations General Assembly recognized the link between human activity and environmental deterioration, the concern for future has called for a dedicated organization. This establishment is formally known as the World Commission on Environment and Development (WCED). The chairman, Gro Harlem Brundtland was appointed in 1983. The mission of the Brundtland Commission was to band together countries to pursue sustainable development. After releasing the Brundtland Report in 1987, the commission officially dissolved but the report has defined the term ”sustainable development” which is still referred to and alluded. (1.) Brundtland herself states,"..[sustainable development is] *development that meets the needs of the present without compromising the ability of future generations to meet their own needs*." (2.)

In the European Union and predecessors in line there is and has been a strong, comprehensive environmental policy in power since the adaptation of the Environmental Action Programme (1973). Sustainable development earned its place in the policy in 1988 as “sustained growth”. (3.) The EU has committed itself towards sustainability and launched the first Sustainable Development Strategy (SDS) in 2001. The Strategy also took into consideration phenomena such as ageing in developed countries, climate change and growing wealth gap. The political environment has also significantly changed with e.g. new Member States accession, terrorist threats and world economic changes. Responding to these abovementioned issues, the European Commission adopted a renewed strategy (EU SDS, 2006) focusing on widening the approach on sustainability. (4.)

The next milestone was the adaptation of the Review of EU SDS (2009), to reinforce the significance of the coming Lisbon Strategy (or Lisbon Treaty, 2010). The Europe 2020, a current strategy, embraces employment and sets sustainable development as a base of economic growth by raising resource and energy efficiency. (5.)

Today, sustainability is an engineering-based comprehensive philosophy that focuses on renewability and on limiting the human effect on the environment. It has become the leading energy and construction policy in the development-enhancing countries. The concept comprises three pillars or core values: economic, social and environmental and their three combinations. Finally, the cross-section of all sub-aspects is defined as sustainability. (6.)

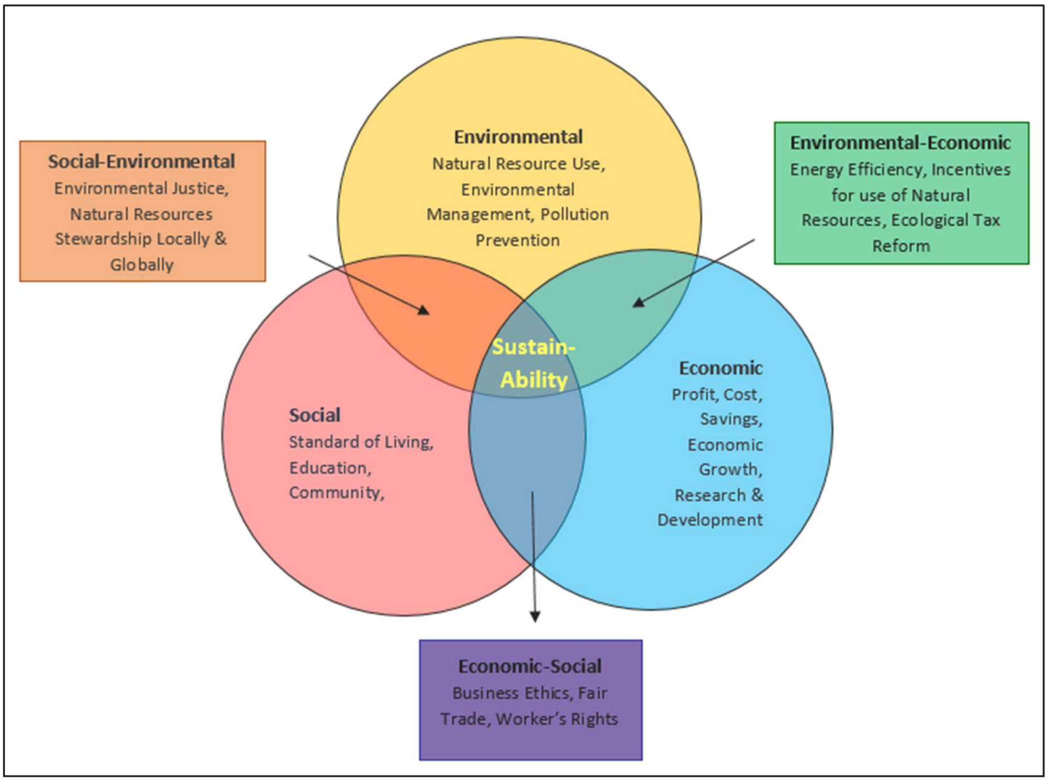

Figure 1. SustainAbility 2002 concept adopted. (6.)

Since the presented core values (Figure 1) are conjoined, preparing a sustainable project, whether a residential house, a campus, an office building, or a pre-school, weighs all the values equally important. As implied in Figure 1, the combinations such as legal, cultural environment, value-based social and other aspects greatly influence the project's outcome: the ability to sustain. (6.)

According to Pérez-Lombard et al (2007), energy consumption of buildings engrosses up to 30-40% of the worldwide energy consumption. Additionally, between 1984-2004, primary energy consumption grew by 49% and CO_2 emissions by 43%. (7.) These rates are derived from economic data, industrial growth, the common use of HVAC systems and the expansion of the residential sector. By then the trends were foreseen as continuing, raising awareness on a needed transition: building and construction technology needed a new approach and new benchmarks.

The 2017 edition of International Energy Outlook verified the growing trend on energy consumption and predicted further a increase. (8.) However, the energy consumption-related CO_2 emissions have shown a declining trend in the OECD countries since 2008. This is a major consequence of the utilization of renewable energy sources and energy efficient means. China, shifting away from coal towards renewable energy sources, will influence on the trend. Figures 2 and 3 introduce the prognoses done by EIA until 2040 regarding these two major benchmarks: sectoral world-wide energy consumption and, seemingly controversially, the decline of CO_2 emissions.

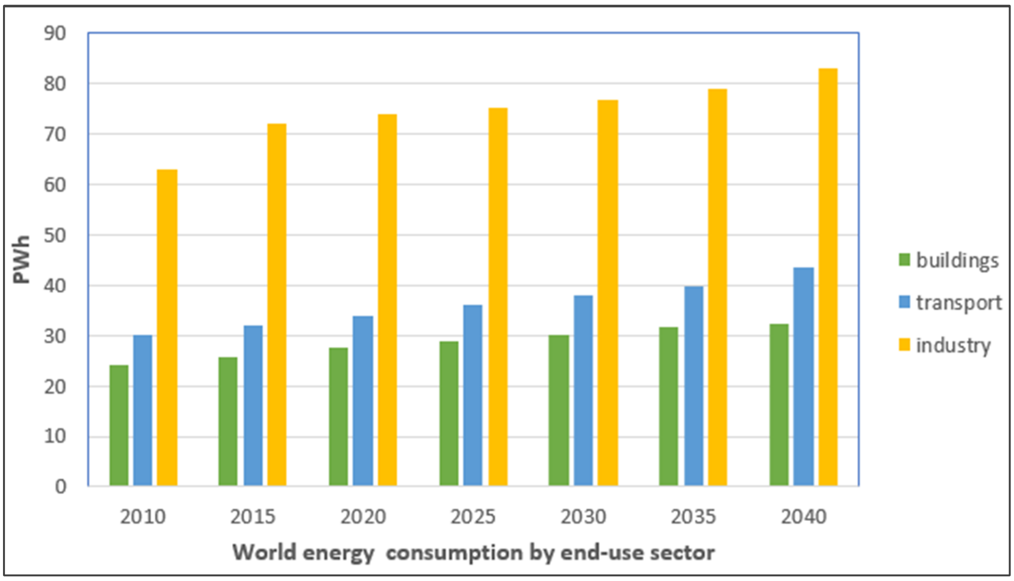

Figure 2. Sectoral end-use of worldwide energy consumption, unit modified. (8)

Figure 2 clearly expresses the expected constant growth of hunger for energy but energy efficient policies in all large sectors can significantly decrease CO_2 emissions (8).

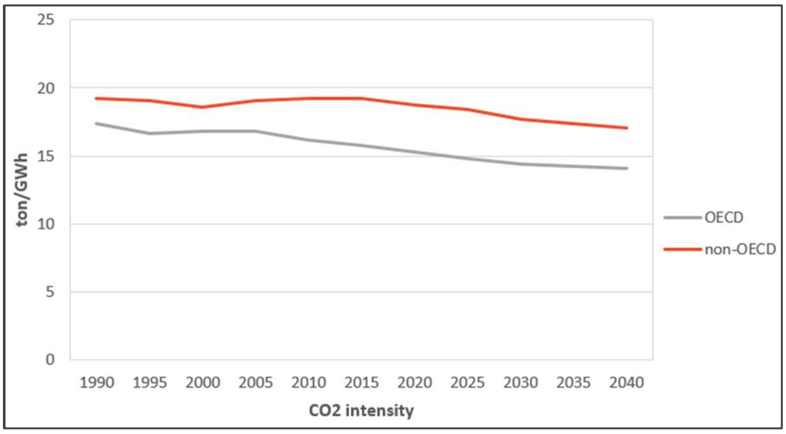

Figure 3. Energy consumption-related CO_2 emissions worldwide, unit modified. (8)

The new, sustainability-focused benchmarks that were emphasized by Pérez-Lombard (7) include CO_2 and other greenhouse gas emissions, energy-efficient operation methods, enhanced use of renewable energy sources, recycling, controlled and possibly limited heat/energy loss to the environment. Various international and national frameworks, building standards, certification tools, regulations and acts exist that serve the same purpose: the achievement of passive and/or active energy-efficiency. The passive method regulates the use of energy-efficient building elements, such as high thermal quality envelope insulation, low U-value window frames with multiple glazed and gas-filled window panes, in order to reduce energy consumption for heating and cooling. The active method, on the other hand, aims at real-time consumption reduction through automation, energy management and optimization tools in the physical and digital building services systems. (9.)

The European Union has passed a directive on new constructions to be nearly zero-energy by the end of 2020 (Energy Performance of Buildings Directive, EPBD). All new public buildings must be nearly zero-energy (nZEB) by 2019.(10.) The EPBD orders to design the future buildings with minimal energy consumption, increased amount of locally generated energy and efficient building systems, including envelopes. This requirement is a directive: a binding legal act that requires the Member States to reach results according to efficiency principles, but the individual methods are not defined. National governments are expected to embed the directives into their own legislation system so they become binding. The Finnish Building Code (FBC) was amended by 1 January 2018 on the bases of the EPBD requirements. However, as the former FBC already consisted of nZEB-based instructions, enacted in2013, the main changes in Finland outline a new energy calculation methodology and a more common use of renewable energy sources. (11.)

Other sources of energy efficiency design instructions may be found in building councils and independent committees, producing their own standards of efficiency. These standards typically set higher requirements than the national legislation to ensure higher quality and performance. The more stringent set of requirements helps to preserve the energy value of the buildings and raises awareness in the legal and industry-specific environment as well. Finland's best-known committee is called Green Building Council Finland (FiGBC, 2010), a member of the World Green Building Council (WGBC). The mission of the national councils is to encourage participants (consulting companies and constructors) to enhance the sustainable building policy in local projects and to assist the participants. (12.)

There are various, sustainability-based energy policies that emerged as a reaction to the worsening environmental damage statistics. A few of them are green buildings, zero-energy buildings, nearly zero energy buildings and passive house standard. They differ in requirements, but the direction and purpose are the same: to build and operate the facility with the least imposed environmental effect possible, but in the most functional and comfortable way. Simultaneously, several certifying institutions came to existence after the official recognition of sustainability, producing various standards, rating systems and certifications. The best-known ones are LEED (US), BREEAM (UK), PHPP (Germany) and Energy Star (US).(13.)

In Scandinavia, the Nordic Built is a noteworthy association. It was initiated by the Nordic Ministers for Trade and Industry to “demonstrate world-class solutions” of sustainability from a Nordic point of view: in regards of location-specific strengths and climate challenges. (14.)

1.2. Aim of the Study

In the last few decades, construction technology has gone through a revolution, due to the takeover of information technology-based tools. This shift has fundamentally changed both the design process and contract trends: the construction industry has moved towards performance-based contracts of design and construction work; the design process of buildings has become entirely digital and post-construction optimization has also emerged. Digitalization has, without a doubt quickened the processes, assisted in achieving better quality buildings, but also revealed new problems and sources of risks. (15.)

A building permit in Finland is granted upon a design based on preliminary estimations and simulations. Therefore, the creation of a realistic and factual dataset on the envelope and energy performance is vital. Energy is used from the first day of occupation, and it is critical to verify whether the installed system performs according to the expectations or not. The difference between calculated and provided energy consumption is a well-known problem: it is called the performance gap. (16.) Based on a re-analysis of 100

LEED-certified buildings, the researchers found that the buildings used in average 18-39% less energy per floor area than conventional correspondents. However, 28-35% of the stock used more than their conventional correspondents. It shows that the green building design has the potential to save energy, but the schemes need further elaboration. (16.) To approach the problem, the root reasons must be clarified. Numerous researchers have submitted their own results, coping further clarification.

Torcellini et al. have also conducted an evaluation on six sustainable buildings. They all performed better than standard ASHRAE-practice, but could not live up to their design assumptions. The authors claim the difference originates from several factors: the design has underestimated the user load and occupancy duration, as well as the users acceptance of the installed system. The buildings do not operate ideally: they use more energy and produce less than expected. (17.)

Additionally, Baylon and Storm investigated twelve LEED-certified buildings and compared them to non-certified counterparts in the same climate region. According to their findings, design mistakes, such as overexposure to daylight glazing, overestimated mechanical equipment and the lack of professional maintenance/follow-up, degrade the potential performance. The energy use per floor area was not more than 15% lower in the LEED-buildings, which is a relatively small difference in respect to such an all-embracing standard. (18.)

The examples above are the result of a small dataset, yet they underline the very existing problem: the difference between design baseline and actual energy use. Ideal performance is predicted by energy modeling simulation software and assumed that it will perform in reality as expected. To justify the actual energy use, a designated verification process shall be carried on: this thesis aims to research this verification process.

All green building-certificating institutions have recognized the necessity of a verification process through monitoring and performance-based adjustment. The process is known by several names: POE (post-occupancy evaluation, Scotland, UK, US), M&V (measurement and verification, US Government), MBC (monitoring-based commissioning, LEED), commissioning and handover (BREEAM). The subject of this thesis is the design-based performance and monitoring tool which was extended in LEED certification guide, version four (2013). The activity is called as “Enhanced Commissioning” and it is awarded with 2-6 points in maximum. The LEED reference guide considers enhanced commissioning as a refined update of building energy services commissioning and gives general guidelines for completion as well. (15.)

However, LEED does not provide any further plan in the procurement phase. Monitoring design is required to submit based on energy simulations and executed through a building energy management and automation system. The main purpose of the thesis is to introduce the links between energy management, automation, monitoring and commissioning. Another goal is to propose a practical and realistic plan for procurement documentation for a project company aspiring for a LEED certification.

1.3. Structure of the Thesis and Methodology

The thesis is divided to seven chapters. Introduction of the thesis introduces the concept of sustainable development and a review of the legal environment together with a present situation of building certificates. It also sets the subject of the thesis: a synergy between energy monitoring, the problem of performance gap and a suggestion for a solution. Introduction is based on literature research and some interviews. After a thorough initiation, the thesis opens up the background and principles of energy certificating, and specifically LEED as a substantive certificating system. This chapter is supported by literature research. Chapter 2 goes on towards the focus point of the thesis: monitoring based commissioning is discussed in depth, both the general concept of certification industry and the existing application in LEED. The main sources were the LEED Reference Guide, interviews, and subject-specific online research. The next, 3rd chapter introduces the main components of the monitoring process: building information systems such as automation, energy and building management system. Chapter 3 supports a deeper understanding of the connections between the systems. In addition, the influence of different algorithms, range values, settings and sensors of automation on the digital base for a sustainable design are explained. In the following, 4th chapter, the thesis brings up post-occupancy evaluation tools: energy metering calibration and building simulations. The methodology is literature research and several simulations in Riuska. Chapter 5 of the thesis discusses the necessary attributes of a procurable, monitoring-based commissioning plan, in the light of the preceding information. To produce this part, extensive literature research and interviews have been conducted. The 6th, analysis chapter discusses the findings alongside with current problems and possible future development directions. Finally, Chapter 7 concludes the study.

2 Monitoring Based Commissioning

2.1 About MBC

Monitoring Based Commissioning (MBC), as mentioned above, is not exclusively a LEED activity, other certification tools, smart building guides and facility management professionals are also familiar with the importance of energy measurement and control processes. The requirement to live up to the design efficiency and possibly optimize it is a universally essential scope for all kinds of facilities. When the building performs as expected, a variety of different degradations will dismiss: indoor environment quality decline, waste usage of energy, early deterioration of the service system and building structure. To obtain this rather complex goal and to react to the reoccurring problem of energy performance gap, a proactive type of tool: monitoring based commissioning was developed. (15.)

2.1.1 Definition

MBC may be defined in multiple ways. On one hand, it is a complex *digital data tool* for measuring, following and concluding real-time building energy consumption, to enable adjustments on the operations for better results. (19.) On the other hand, it is a quality assurance tool to improve the way buildings are used and maintained, with the assistance of available technologies. (20.) Alternatively, it is a *comprehensive business model* to persuade the rate of return of the investment in improved efficiency (15.)

As the entire monitoring operation is based on constant comparison – this is the verification – between design data and real-time consumption, MBC can be perceived as an operations phase activity for existing buildings. Achieving and maintaining the best possible control over the facility requires preparations starting from the fundamental commissioning process. Figure 4 introduces MBC as an overall process, including the main systems and their functions. The process consists of three separate systems: an operative system (building automation, BAS) a reporting system (energy management, EMS) and a maintenance system (BMS).

In nutshell, the process operates around the three main systems mentioned above. The first two functions, HVAC automation and energy management are launched in the design phase, the third function, maintenance in the operations phase. They all operate during the entire lifetime of the facility and their functions are connected to each other: an error in one will have an impact on the other two as well.

MBC	control and automation - BAS	data collection	data transmission
		HVAC control	faults and alarms
	building energy management - EMS	monitoring	verification
		trends	decision support
	building management - BMS	maintenance	ticketing
		limited system access	local problem solving

Figure 4. The present structure of Monitoring Based Commissioning and related activities. Source: own findings based on LEED v4 Reference Guide.

Automation (BAS) controls the facility's internal conditions, which include subsystems such as heating, cooling, ventilation, lighting, domestic hot water, safety and fire control. Other tasks of automation are to transport the registered data to a remote database, and to send alarm signals based on programmed conditions to the building operator. *Energy management* (EMS) monitors the processes and consumption, and it is used as a dashboard for the energy manager to conclude trends and long-term usage profiles. EMS tracks the specified data-points that were assigned from the automation system. *Building management* (BMS) is responsible for the local maintenance, alarm resolution, physical reparation. Maintenance software are meant to identify issues before an actual unexpected happening would occur. (21.)

Each building has its own operation way, special conditions (due to the function, way of usage, environmental loads, system principles etc.) and requires a thorough understanding on the produced operation data. In every case, the automation and monitoring system needs individual fine tuning, testing and frequent adjustment. No pre-set tool or product is capable of controlling the processes without a careful preliminary assessment. Continuous monitoring requires full engagement and commitment both financially and professionally from the owner and the commissioning team. Any monitoring-based commissioning process costs money, it is not enough to install and set out the HVAC and other systems. It requires cyclic development on the facility, on the measurement process and other components. Without further investments the system will not fulfil the expectations on improving the performance and saving energy. (20.)

Monitoring based commissioning is primarily and information technology-related activity. Boban Ratkovich has summarized the key components of a functional measurement and verification process. (15.) The components are discussed in depth in the chapters below.

- Building a Direct Digital Control System – to control the field equipment (Chapter 3.1)
- Data Acquisition System and Remote Database – to collect and store DDC and energy-meter data for EMS analysis (Chapter 3.1)
- Energy Management System (analysis software) – used for calculations, to analyze trend logs, to create baselines (Chapter 3.2)
- End-use Sub-metering – to determine and track sub-system performance for verification (Chapter 4.1)
- System Calibration Tools and Energy Metering – to provide reasonable data for investigation (Chapter 4.1)
- Building Energy Model – to create energy targets that later on will serve as a comparison base (Chapter 4.2)

The verification process is illustrated in Figure 5: the activities connect and create a closed loop with repeatedly updated input data.

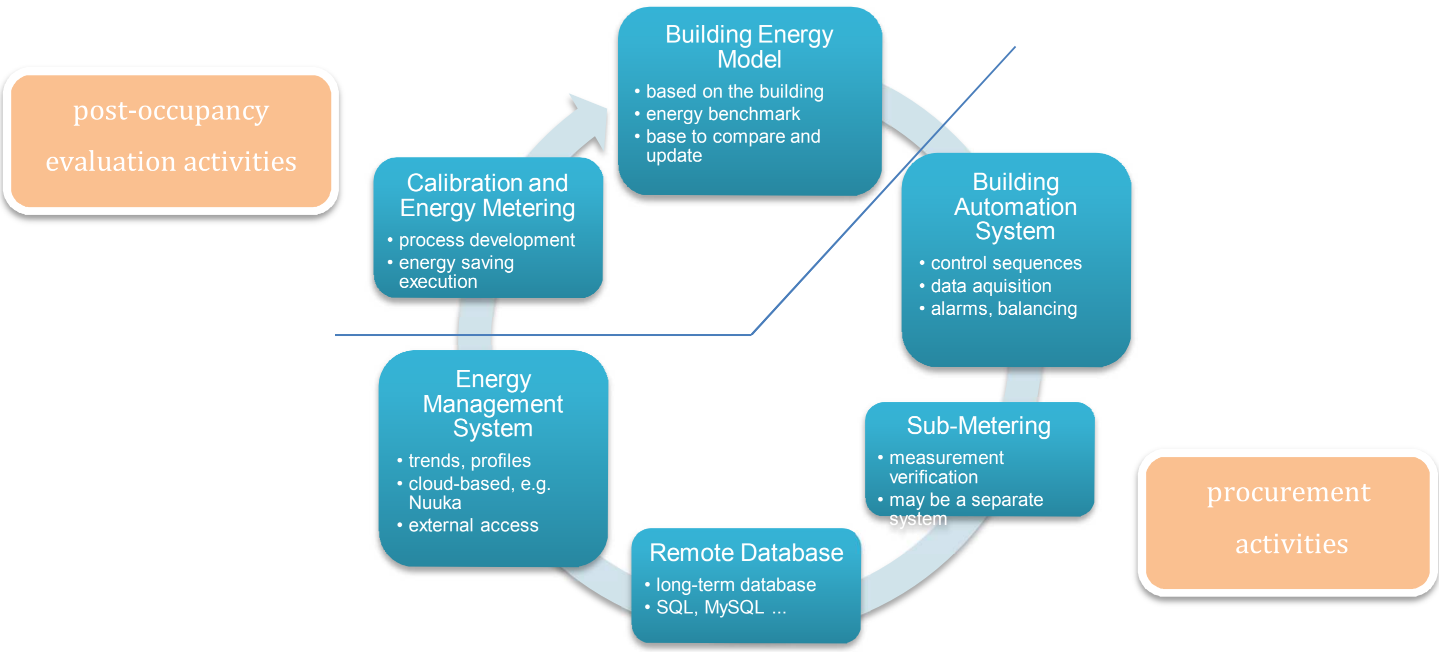

Figure 5. Ongoing verification process, based on Ratkovitch 2012. (15.)

2.1.2 Commissioning Practices in the Market

In the sustainable design and construction market, numerous different companies offer their products and programs for commissioning purposes. Vendors use different terms for principally the same idea: smart metering (pairing electric and gas consumption and generation for lower prices (22)) smart buildings (interconnected building systems to achieve lower overall consumption (23)), energy optimization (in-situ development and utilization of the most efficient energy design of all possibilities (24)) etc. The idea is to identify and utilize energy saving potential of a building. This abundance of products makes it complicated for contractors to ensure the validity of the project's efficiency.

Soft Landings, a construction procurement practice popular in the UK is also meant to be the link between several commissioning processes, both for new and refurbished buildings. The protocol disposes the entire procurement procedure (inception and briefing, design development), the initial occupation (pre-handover, initial aftercare) and post-occupancy evaluation (POE, extended aftercare). Soft Landings has its own Framework (process stages detailed) and Core Principles (leadership, roles and responsibilities, continuity, involvement of parties) to adopt. Monitoring-based activities take place at the extended aftercare, utilizing a building management system (BMS), provided by a separate subcontractor, whose responsibility is to introduce the installed systems to the facility manager. (25.)

There is no Finnish legislation about a standardized commissioning and verification process for energy efficiency. The former chapters D3 and D5 of the Finnish Building Code (FBC) only defined the energy calculation methodology and minimum requirements. The newly enacted modifications remain silent about commissioning. Other chapters in the FBC such as former D1 (water and drainage), D2 (indoor air quality) and currently effective SFS-EN 15232 standard (automation and control) set requirements to the individual systems related to HVAC and building performance. However, since there is no further comprehensive commissioning enactment, best practice is in use, based on the above-mentioned acts and experience.

BREEAM (Building Research Establishment's Environmental Assessment Method) is focused originally on the UK, but by now it is an international standard and a locally adopted certification tool. Monitoring and commissioning also plays a role in the rating, considered as a minimum management standard and is awarded with maximum 4 credits. The credits for “Commissioning and Handover” in the latest, 2016 version are divided between

1. Commissioning and testing schedule and responsibilities
2. Commissioning building services
3. Testing and inspecting building fabrics
4. Handover. (26.)

These scores are prerequisites of each other, to ensure a full completion of monitoring. Point 1) and 2) ensure the presence and use of an advanced building services-controlling system, including tests, handover and post-handover stages. BREEAM’s commissioning practice is based on CIBSE Commissioning Code (Chartered Institution of Building Services Engineers, 1976, UK) and it seems that in Finnish practice, it is supplemented with EN standards.

2.2 Fundamental Commissioning Process in LEED

LEED (Leadership in Energy and Environmental Design) is a comprehensive tool launched in 2000 by the US Green Building Council. It is developed to promote better operating, more energy- and resource efficient buildings, covering both renovations and new constructions. The philosophy is built on sustainability: the synergy between a facility, environment, designation and users. A LEED certificate verifies and validates the green features, design, overall operations and sustainability of a building or neighborhood. In order to earn a rating, the building must fulfil certain requirements. The requirements are always the extended forms of basic, non-awarded prerequisites. A project building may be certified with one of the four different labels: Certified (40-49 points), Silver (50-59 points), Gold (60-79 points) or Platinum (80 points and above). LEED has published its current, 4th edition guide in 2013, giving further instructions on water efficiency, material choice, smart grid thinking and performance-based design. (27.)

The Guide disposes 8 different fields, which are Location and Transportation, Sustainable Sites, Water Efficiency, Energy and Atmosphere, Materials and Resources, Indoor Environmental Quality, Innovation and Regional Priority. (28.)

Commissioning is an overall process to ensure that the procured building services systems are built, installed, calibrated and work according to the scopes and design of the owner. Basic commissioning is the first prerequisite for the Energy and Atmosphere chapter, by the name Fundamental Commissioning and Verification. Being a prerequisite, completion does not award any extra credit for the project. Fundamental Commissioning process (Cx) serves as a foundation for a possible extension to achieve credits. (28.)The scope is to oversee and complete the commissioning process for the building services systems that reflect both Owner's Project Requirements (OPR) and Basis Of Design (BOD), according to ASHRAE 0-2005 and 1.1-2007 Guidelines or corresponding Best Practice. As it is mentioned in 2.1.2, in Finland there is no compiled EN standard for commissioning, therefore a combination of EN-standards on the building systems and the ASHRAE Guidelines seem to be possible to utilize.

To direct the commissioning process in construction field, US Government has issued an ASHRAE act, 0-2005 Guideline. The Guideline orders Cx according to the specific design phase: pre-design, design, construction, acceptance, occupancy & operations. LEED adopted the act and integrated to the Cx. According to this act, the commissioning authority (CxA) may start immediately at the pre-design phase but joins the process when the basis of design (BOD) is confirmed at the latest. The design is confirmed when the design team has submitted a clear technical guidance about the structural, building services and thermal performance, by the assistance of building simulations, in accordance with the owner's requirements. The appointed person must have documented experience of at least two building projects with similar scope of work. In the basic commissioning case, CxA may be a qualified employee of the owner, an independent consultant or part of the design team. The true value of Cx lies in the verification that the goals of the owner are met and the building performs as expected. (29.)

Commissioning Authority's (CxA) s main responsibilities may be summarized in the following points:

- Prepare, update and execute the Cx plan based on the design, which includes all HVAC, energy and building services testing and functioning related tasks.
- Ensure compatibility of the Cx and construction documents with a construction checklist developed. This checklist serves as a verification for the commissioning team that during construction phase the installation is executed according to the intentions.

- Develop a functional system test procedure and execute it. During the execution CxA must follow all the processes and book the issues and benefits, to prepare a final report.
- Compile an Operation and Maintenance Plan: the technical summary of all building operations and automation. (28).

2.3 Enhanced and Monitoring Based Commissioning in LEED

LEED specifies a strategy to extended commissioning. In the LEED guide it is called “Enhanced Commissioning”, which is worth of 2-6 points. The commissioning process and available points are illustrated in Figure 6.

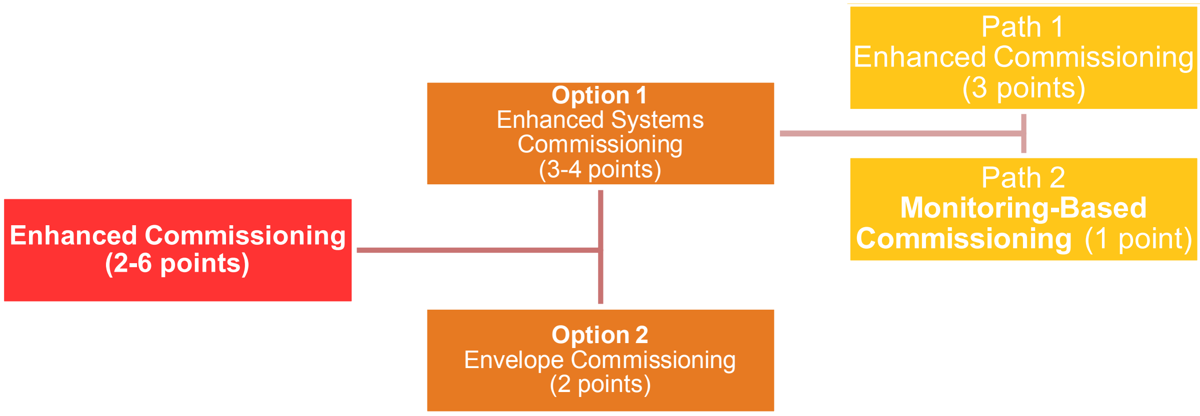

Figure 6. The structure of the conditions for receiving points for Enhanced Commissioning. Derived from LEED Reference Guide (28.)

The goal of the enhanced commissioning is to provide a more efficient and stringent monitoring and maintenance. An important difference compared to the basic commissioning is that the procuring person cannot be employed in the same company as the designers nor contractors. (28.)

The LEED guide defines two possibilities for the entire Enhanced Commissioning. The first option is called Enhanced Systems Commissioning. When achieved, the project can be awarded up to four points in total. Option 1 includes two subcategories: Enhanced Commissioning, for the award of three points and an additional subcategory, Monitoring-Based Commissioning, for one point. This section focuses on the activities of active systems, such as HVAC-related construction, operation and supervision. (28.)

The second option is another, independent one: it is called Envelope Commissioning (2 points) and relates to the design of the envelope through various element tests. (28.)

The main tasks of option 1, Enhanced Commissioning include, naturally, the basic activities but also:

- revision of the HVAC construction plans
- confirmation of the contractor's choice on the equipment
- planning of maintenance training
- system revision during ongoing commission. (28.)

The second option defines Envelope Commissioning (BECx)of the thermal envelope. It is a beneficial addition for any project where the role of the envelope is crucial, such as in the Nordic climate or where the risk of leakage or infiltration of contaminants is high. Therefore Option 2 requires a completed documentation of the envelope, including seasonal testing, a review after 10 months of completion and a verification of occupant training and effectiveness. Tests include air and water infiltration, exhaust air re-entrainment, thermal performance, envelope pressure, air leakage and daylight glare control. (28.)

3 Building Information Systems

There are several information systems to manage a facility's operations: building automation system (BAS), energy management system (EMS) and building management system (BMS). Due to the similarity of the labels, it is easy to mistake them for each other. The difference lies in the functions and the extent of control.

3.1 Building Automation System

BAS is a network of integrated computer components that controls building operations such as HVAC, security and access control, lighting, electricity and fire safety control. The core function of automation is to keep the climate conditions of a space (temperature, humidity, pressure and ventilation) within a specified range, based on an occupancy schedule. BAS also alarms the maintenance person in case of failures. (30) BAS does not record or report any data, it is a real-time control tool. BAS is needed practically in every larger facility and it is included as a prerequisite in LEED, subsection Fundamental Commissioning and Verification. The LEED guide defines an automation system as "a control of equipment which uses a minimal amount of energy to maintain setpoints and comfort levels". (28.) BAS consists of two main components: DAQ or data acquisition and DDC or direct digital control. In Finland the SFS-EN standard (EN 15232:1 and 2) enhances building energy performance through BAS control: it sets functions and minimum requirements for any new installed system. The SFS-EN standard estimates that the energy savings are up to 30% when applying a BAS.

Data acquisition (DAQ) is a measuring and communication process conducted with a computer and sensors. The measured phenomena may be of physical or electrical in nature, such as voltage, current, temperature, sound, light, pH, flow, force and pressure. (31.) Data acquisition needs an interface, a transfer program enabling the flow of conditioned signal data inside of a system. The communication is defined within a network, such as Ethernet, ARCNET or LonWorks and a protocol (such as BACnet, Modbus, TCP/IP, LonTalk). Acquisition signals usually use 4-20 mA or 0-10 V between sensors and controllers. Controllers communicate use the method to communicate with each other and the work stations. (32.)

Fault detection and diagnosis (FDD) is a key software component in all automation systems, serving the purpose of alarms and fault management, operating by a constant comparison of the running model to a fault-free condition model. (33.) The particular definition of *fault* as a problem, error, symptom and root cause and the developed reaction or response given to them construct the alarm system for BAS. *Detection* stands for the quantitative or qualitative recognition on an occurred problem in the controlled space. *Diagnostics* takes place when some corrective action is implemented, in pair with fault isolation. (34.)

The literature notes multiple approaches to FDD, differentiating simpler models (pattern recognition) and rather complicated ones (neural networks), passive models (routine scanning) and active ones (testing, procedural), as well as hybrid (combined) models. The main purpose of all FDD systems implemented is to help to identify a potential source of failure before it occurs. Implementation has multiple potential risks apart from common software complications, such as interface, system integration, generic libraries etc. Specific FDD issues include noise filtering (sensor data), novel faults (assumptions that were earlier not considered), knowledge visibility and sensitivity problems: that is the balance between sensitivity versus false alarms. In practice, this last one calls for fine tuning and multiple attempts of threshold setting. (34.)

A sophisticated FDD alarm system helps to detect deviations from a preset trend. After detection, the system is able to give a few possible options to the operator to react. The reaction may affect both the numeric values controlled by BAS and the physical condition of the equipment. The detectable faults include simultaneous heating and cooling, underutilized free cooling potential, incorrect fan speeds, pressures, incorrect refrigerant and oil levels. In a long-term management strategy, FDD enables continuous retro-commissioning and pinpoints cost-optimal timing for facility upgrades, as by default the energy efficiency of any equipment will degrade. In the future, FDD is expected to give a prognosis to the building operator about the remaining useful life of any equipment in the service systems, a comparison of investment needed in prompt versus deferred intervention. By functions provided, FDD has the potential to become a core part of EMS. (35.)

The importance of a well-designed and commissioned automation system is inevitable: BAS is the safeguard tool to ensure the desired interior conditions in buildings are met and maintained. Figure 7 summarizes the core purposes of a functional BAS.

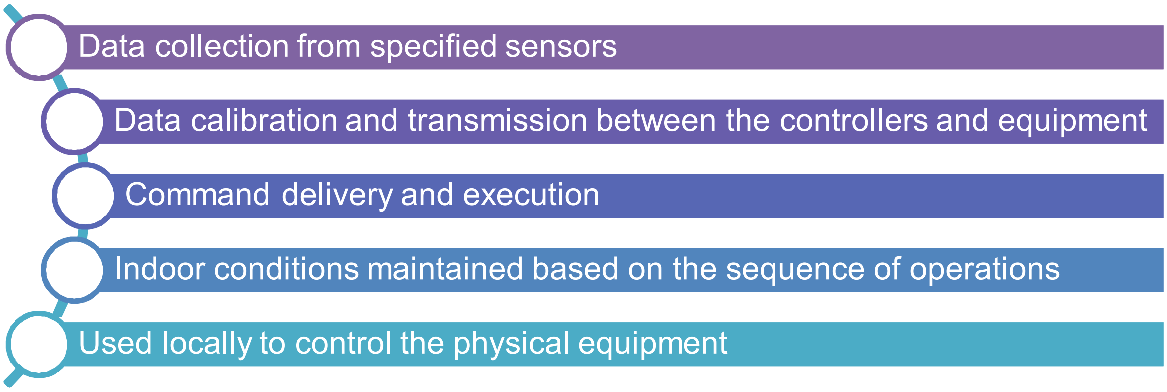

Figure 7. The main purposes and activities of building automation. Own finding.

From practical, project MBC point of view, automation design and implementation is affected by the main factors listed below:

- Size of the project: in the case of a smaller building all the consumption data may be directly measured by the automation system (traditional solution). For larger facilities, it is advised to build up a separate measurement system and connect the readings directly to the automation. (36.)
- In both of smaller and larger building cases, the internal communication flows in TCP/IP channels, only internally visible. External connection to EMS/BAS supervision is supported by a modem and protected by a firewall. Protected Internet/VPN-connections ensure the safety of external information transfer. (35.)
- Data points for control may be verbose (up to 500 points/equipment). Therefore, the most important data points need to be selected for EMS use. The selected points concern energy consumption or process information in the controlled spaces, evaluated locally or globally. Local evaluation describes the controlled spaces specific conditions, e.g. temperature of exhausted air and global evaluation aims to give general, external information around the system. Outdoor temperature is a typical global indicator. (32.) Figure 8 is a screenshot taken from an installed BAS to illustrate the data points and their locations for data collection of the ventilation system operations and consumption.

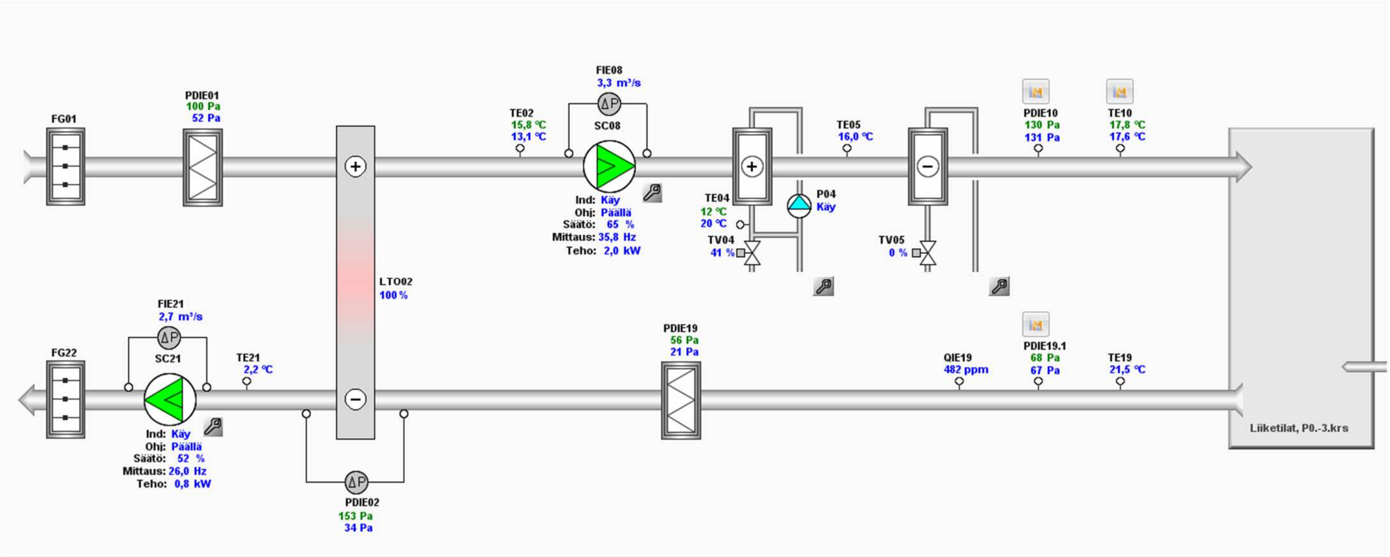

Figure 8. An active, operating BAS using selected points of a ventilation system. Service provider: Arealtec

- As it is visible from Figure 8, the selected data points for ventilation typically include:
  - temperature of processed supply air to blow into and exhausted from the space (local, process, 2 points)
  - pressure measurements of filters on both supply and exhaust channels (local, process, 2 points)
  - supply and exhaust fan volume flow, pressure difference and electricity consumption (process 2 points, energy meters 2 points)
  - exhaust air CO_2 sensor (local, process, 1 point)
  - heating and cooling coil valve position (local, process, 2 points)
  - efficiency rate of heat exchanger (local, process, 1 point)
  - external temperature (global, process, 1 point).
- BAS communicates in one of the following ways, depending on the building size:
  - separately between meter, meter collector and controller (bigger system)
  - between the remote database (for EMS purpose) and the automation.

The list above clearly shows the complexity of data collection during project execution. Data separation and classification, based on relevancy is vital: further steps of the project and verification process will continue with the findings submitted from the automation plans. (36.)

3.2 Energy Management System

An Energy Management System (EMS) is a proactive reporting and supporting tool which monitors and improves the performance that BAS on HVAC provides. It gives real-time insight through fast dynamics models, short-time simulations based on the sensors about the system performance and possible adjustments. Additionally, it controls and optimizes the generation and/or transmission system. The system serves as a dashboard to keep long-term energy data, track trends and logs, analyze and support the decision-making. (37.) LEED evaluates EMS as a core part of Enhanced Commissioning, assisting monitoring and evaluation processes. (28.) The main features of a functioning EMS are real-time monitoring or verification, communication, possibility to prompt interference and remote control and long-term data storage. To ensure these conditions, the EMS requires an internal communication protocol and a remote database on a server, with constant real-time operational (internal) and weather conditions (external) data loading. (38.)

In practice, it is often difficult to explain the purpose of the EMS to building owners. It is not mandatory in Finland to use a monitoring system – monitoring can be done manually as well. To get the confirmation to install an EMS the best method is to compare the existing building's current consumption to a possible better result. For new construction, the earlier a monitoring system is accepted, the cheaper it is to design and install. (36.)

Figure 9 summarizes the core elements of a building energy management system.

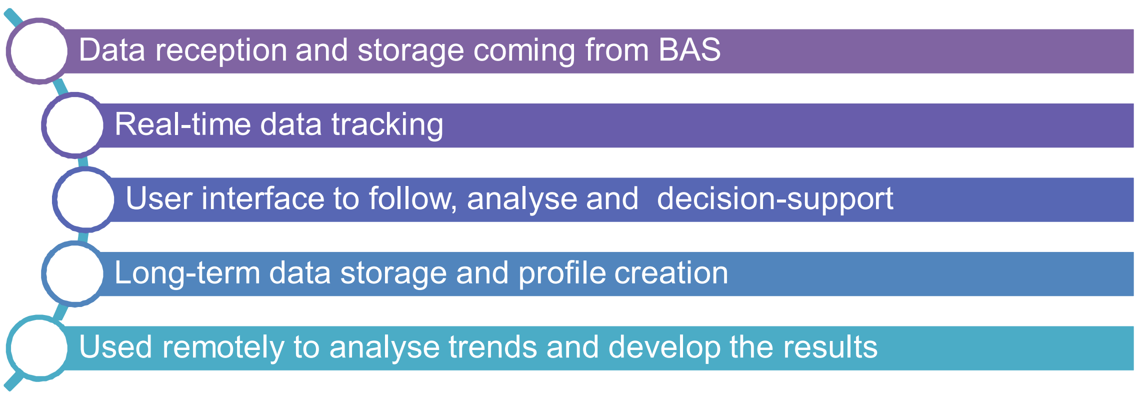

Figure 9. The main tasks and activities of the energy management system. Own finding.

From MBC project management point of view, Energy Management System is vital to agree with the project owner and get to install, as it:

- receives and processes the data coming from automation
- creates trend logs and analyses
- provides a long-term data storage for the future comparison of data
- works through remote access
- access is protected and given to a limited circle of users
- data protection is ensured
- serves as the second pillar in the MBC process. (36.)

3.3 Building Management System

Another digital tool, Building Management System is a software for facility managers and building maintenance staff. Traditionally, maintenance has included paper-based system manuals, equipment operation manuals, tables of setpoints with sensor locations, trouble-shooting tables etc. In case of an equipment breaks down, service is ordered through ticketing for replacement or reparation. (36.) Figure 10 introduces the differences between traditional approach and software-based building maintenance.

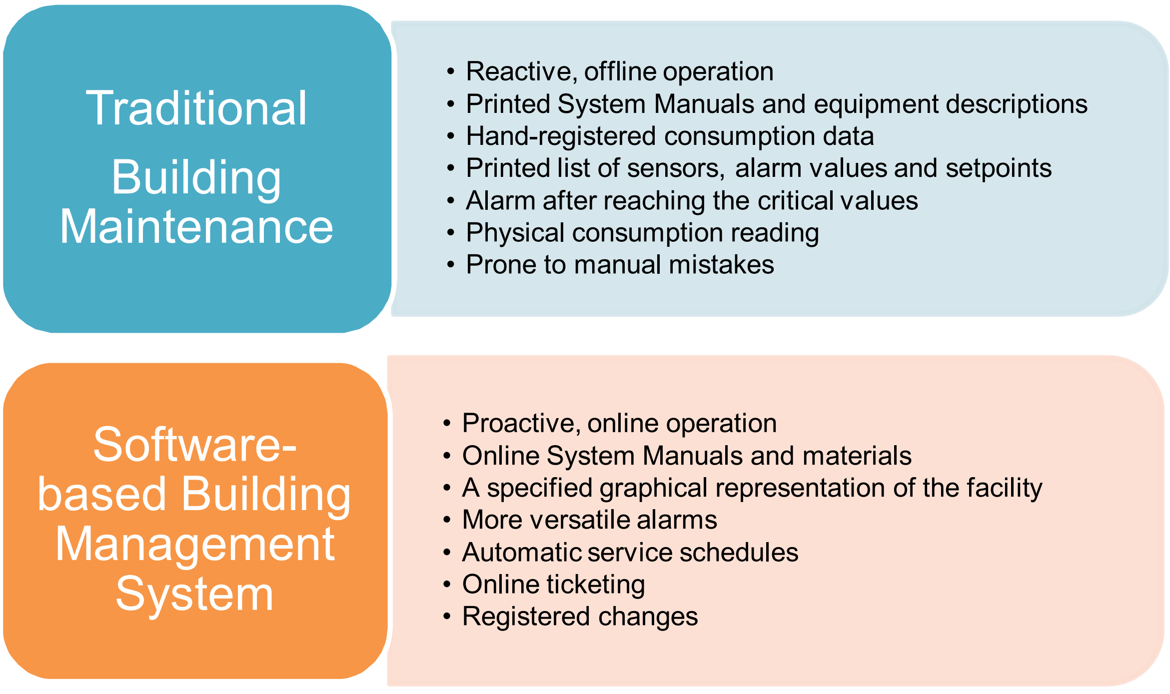

Figure 10. The comparison of traditional and software-based building management. (39.)

Utilizing existing digital tools, e.g. a combined platform of BAS and EMS with BMS, with limited access and extended design content, troubleshooting tables and issues logs could help the staff to identify the issues quicker in their own competence. (40) This approach is called proactive maintenance: it promises savings due to an earlier recognition of problems and obviates them before they turn into expensive problems. Markets also evaluate the latent potential in BMS software: prognosed trade rates will reach USD 19 billion by 2023. (41.)

According to LEED, there is no obligation to utilize an online BMS tool, only to register the monthly readings to a separate sheet. Therefore, an online version of local maintenance is not compulsory. In practice, larger facilities in Finland are all connected to an online maintenance platform, which is independent from the EMS. (36.) Building Management System appears from LEED's MBC point of view as it follows:

- It serves as the third pillar for ongoing commissioning by providing manuals, settings, schedules, relevant information stored for the maintenance, available online and offline.
- The online systems are used by a dedicated competent person (energy manager) through a remote access, that provides information to the local maintenance staff.

3.4 Current Applications

Nowadays several BAS, EMS and BMS products are available in a wide range in the construction market. The following list gives a few examples of the best known and available companies and their products. Some of the vendors have already launched a combined automation and energy management package, such as Siemens (Desigo, Figure 11), Fidelix (Figure 12), Optergy, Johnson Control, DEOS AG and Schneider Electrics. When separate BAS and EMS are planned to a project, it must be reviewed case by case how the systems will synchronize. In practice, the main purpose of these systems is to discover disfunctions in an early phase in order to generate savings for a faster return of investment. (42.)

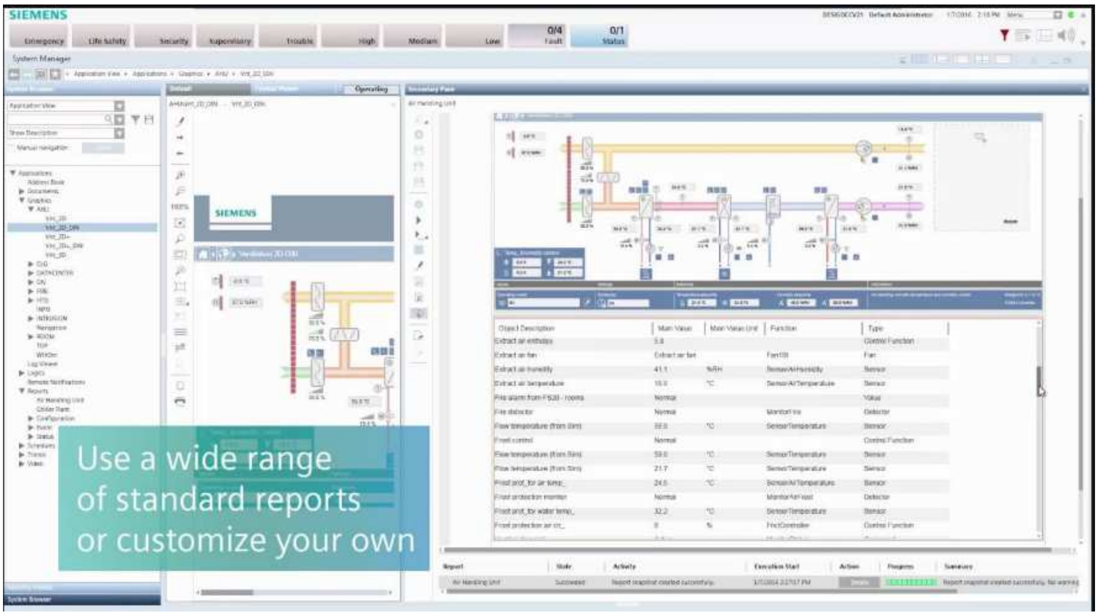

Figure 11: Siemens automation in a graphic display. (43)

The user interface may differ according to manufacturers' own design, but the main function. i.e. the selected data points, energy consumption, external temperare and other relevant data are loaded and accessible for the user.

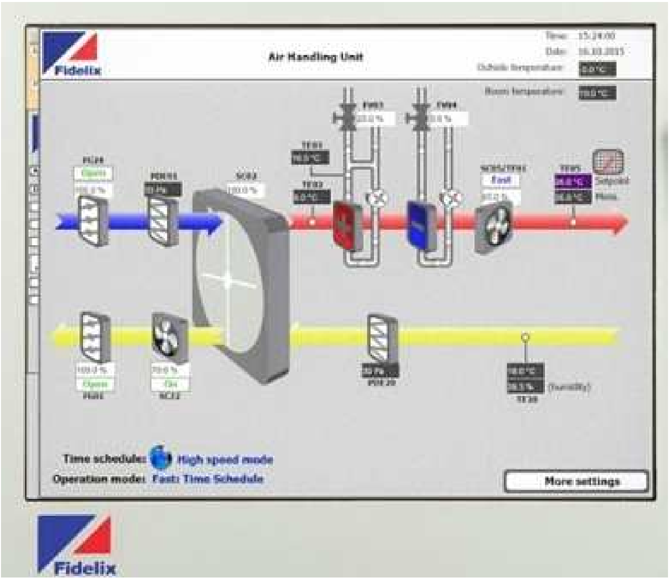

Figure 12: Fidelix automation system.(44)

There are a few practical factors which should be considered when comparing / choosing a BAS:

- Size of the project: the systems and the tools may be in use and serve different scale projects. There is a significant difference between the automation of an office building and that of a single family house.
- Configuration: the extent to which the automation can be adjusted.
- Openness: integratability between different vendors components and systems can be integrated to the chosen system.
- Graphical representation in various forms and devices – according to the appearance of graphics on various screens: tablet, mobile phone or other devices. (45.)

The best-known software in Finland is Nuuka (Figure 13). Other energy management systems include Honeywell (combined with BAS, Figure 14), Schneider Electrics (Building Analytics, EcoStruxure, combined with BAS, Figure 15), Optergy (combined with BAS) and Enerkey.

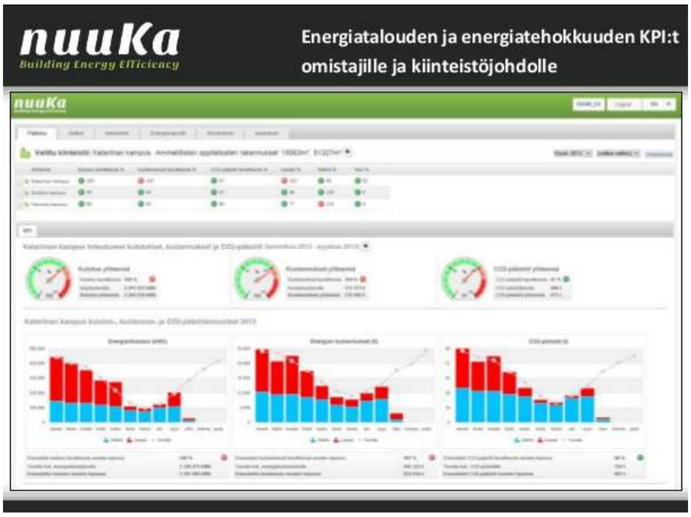

Figure 13: Nuuka Solutions. (46)

Nuuka serves as an external plug for the automation systems used in Finland (36). Other applications can be installed as a combination, e.g. Schneider Electrics.

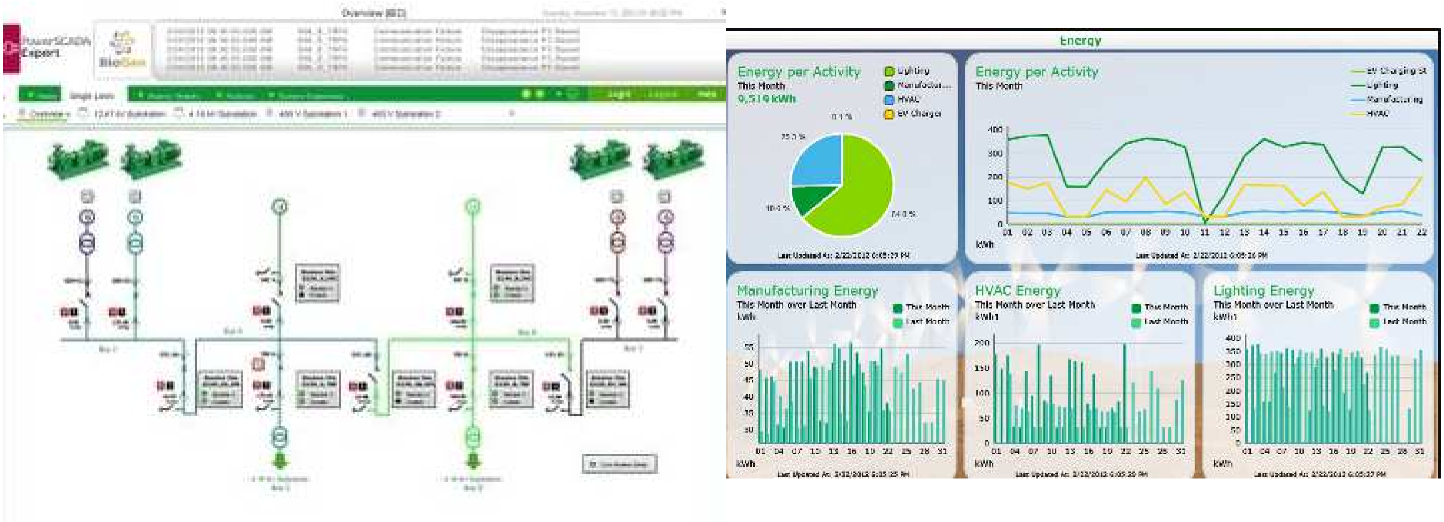

Figure 14. Combined applications in EcoStruxure, Schneider Electrics. On the left, automation of local generation, as part of BAS, energy supply. On the right, EMS analysis. (47)

From a practical point of view, there are a few factors to consider when comparing and choosing an EMS:

- Information to segment, present and sent out in required form – can the assigned person use them according to their functions?
- Is the pre-set and personal trend log creation possible?
- Is the suitability with BAS and metering central unit, in case of different vendors verified? (45.)

Other available building management systems for maintenance in Finland include Haahtela RES, FMX, Buildercom, Fatman and Granlund Manager.

The examples and possibilities above flash the true potential in building information systems. None of the reference guides, such as LEED, BREEAM define the type of building automation and energy management systems, they plainly advocate the implementation and regulate the reporting activity regarding generated building energy data. As the development of artificial intelligence (AI) has accelerated, further integration of digital data services is expected, such as Nuuka's attempt to integrate a fault detection and diagnosis software. (366.)

4 Post-occupancy Evaluation Tools

The continuous monitoring process includes both one-time activities, such as procurement: installation of sub-meters, BAS and EMS, database access (see Figure 5) and evaluation activities. This chapter briefly discusses the necessary tasks that conclude the verification for an occupied building.

As data is produced through measurements and the storage of the specified data points, it is necessary after a certain period of time, usually a quarter of a year to process and analyze the data. This is done through energy metering and calibration as mean data-processing and calibration of the simulation model. (36.)

4.1 Definitions

In the energy efficiency field with various technical and closely related terms in use, it is important to distinguish between sub-metering, system-level metering and energy metering. Metering activities support the measurement and verification (M&V) process of commissioning: sub-metering is a pre-requisite in any type of LEED project facility. Calibration supports metering by providing reliable measurements both on the momentary and the computed update of consumption. (28.)

Sub-metering shows the actual consumption of an active system component in a certain moment of time. It includes electric and thermal power measurements, as well as gas, water and air flow rates. In shared facilities, e.g. residential houses and office buildings it is essential to conduct sub-metering: it allows for the energy consumption to be individually measured and assigned to unit users. (48.) LEED considers building-level metering as prerequisite, serving the same sub-metering purpose of whole-level consumption (see System-level metering). (28.)

In Finland metering activities are provided mainly by Mittrix and Carlo Gazzani. (36.)

System-level metering informs the facility manager about the energy consumption and, when applicable, production of an entire system in a facility. Registering the consumption data to a system-level metering software helps when estimating usage profiles and finding excessive consumption peaks. Additionally, it becomes possible to draw trends, diagnose specific waste areas and, ultimately, reduce energy costs through improved efficiency. Installation of system-level metering is the precondition in LEED Guide for energy metering. (28.)

Energy metering is an advanced mathematical model to effectuate energy savings. The model works with special machine learning methodologies (e.g. Bayesian statistics, SIMEX and Regression Calibration) and is based on the difference of momentary energy consumption between an intervention and the absence of intervention. In other words, it shows how much energy would have been used in the post-intervention time compared to the new consumption data due to intervention. Therefore, the saving cannot be measured directly. (49.)

Calibration is the process of active comparison or “true process” between the measured value or “observations” and computer data or “model”, based on some uncertainty or “standard error” and input parameter rankings. Inputs differentiate between calibration type (unknown specific parameters in the true process) and variable type inputs (controlled or observed inputs). (50.)

In building energy models, calibration is a concept to consider both in the design phase and during ongoing commissioning, both for new constructions and retrofit guidance. The calibration process gives an opportunity to draw up several energy consumption possibilities and thus find the most efficient one. In general, calibration can be done manually or automatically. Manual processes include the physical and operational characteristics of the building, statistical data and environmental parameters. Furthermore, the modeler’s own expertise and judgement is a key influence factor which carries a potential risk of oversights. Automated calibration, on the other hand, relies on computing algorithms: the most common ones are Bayesian-based techniques, utilizing Gaussian Process regression. The biggest advantage of the method is the possibility of simultaneous incorporation of various uncertainties. (51.)

Finding the best model parameters mainly depends on the uncertainty level of the model. Uncertainty level translates as an error. Therefore, the calibration method of this present error has a great effect on the final decision. Figure 19 shows the influence of prior information on the decision-making process.

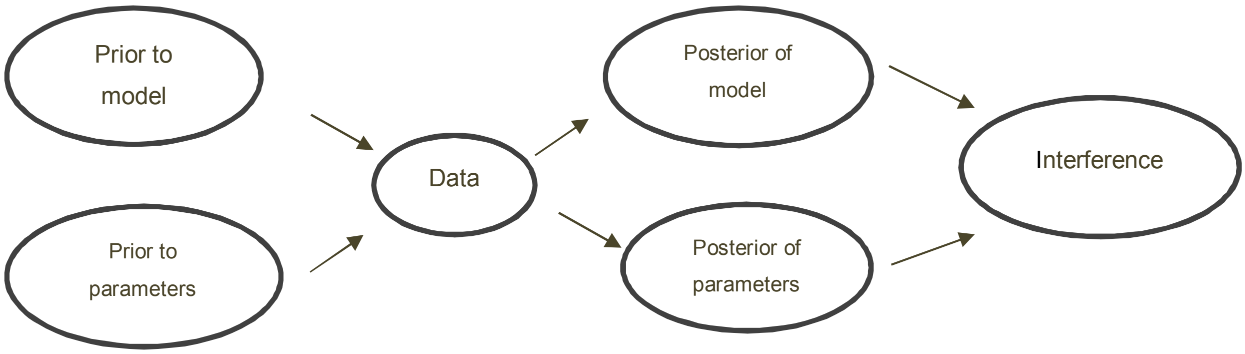

Figure 19. Bayesian model averaging for error calibration. (52)

4.2 Energy Simulations in Practice

Building energy simulation in the design phase of modern construction is an absolute must, in order to attain the energy design and to compare several cost-effective options. Based on the expanding demand, the software options available on market have gone through an enormous refining in the recent years, covering both whole building and partial or task-focused applications, e.g. HVAC simulation, solar gain and wind energy. The whole building-tools have gained a significant popularity also in the post-construction phase of the building life cycle, including both new construction and renovation. (53.)

The whole building energy modeling software options currently in use are typically built to compute the energy demanded to maintain defined criteria, around a full year. The inputs are a synergy between internal, external and dynamic loads. Table 1 introduces the types of inputs used.

Table 1. Type of inputs in building energy modeling. (54.)

External	Internal	Dynamic
location-based: • weather conditions: insolation, wind exposure • ground material envelope-specific: • geometry • envelope materials	required comfort conditions: • space temperature • humidity • pressure	occupancy dependent: • heat load • lighting • demanded HVAC user behavior dependent: • building function • appliances

An important part of the energy simulation is the building automation which is designed with specified ranges of values and alarms but in practice, very often it operates general operational control sequences. According to Ratkovich, if the optimized performance is not considered, these general control sequences possibly corrupt the calculations and result in false baseline for the project design. (15.) The result of a building energy model is utilized as the basis of design. It also serves as the comparison device between the model and reality. LEED certification requires verification a year later, when there is enough data to update the energy model. (28) After concluding new trends on the building services, the model can be calibrated with more realistic, history-based data, giving a better description on the operations.

Building energy models, just as automation models need several fine modifications and updates to be evaluated as functioning and have a few, well defined sources of problems. One of them is calibration of the whole building model, which is needed for validation. Calibration here solely refers to the entire building simulation and not to the individual input uncertainties or parameters. As the existing simulation models do not deal with this calibration, the designer must compare the data between simulation and measurement to conduct the verification calculations. Model uncertainty is the other, commonly known issue: models represent values through broad simplifications and constrained processes. (54.)

5 Monitoring Based Commissioning Plan

As explained in Chapter 2.2, the commissioning process regards both the launching phase (MBCx) and the operations phase (OCx). Since they are joint to each other, in practice it is risky to separate them. Therefore, the following chapter will introduce a summarized, listed plan for both processes, based on the author's own research and interviews conducted with colleagues. Green Building Partners Ltd. has developed their own perception about a universal project building and main activities (ToRa, Toimiva Rakennus), which can be seen below (Table 2). LEED-based, commissioning-related activities are paired with different stages to ensure the successful co-operation in project management.

Table 2. Construction phases and regarding MBC documentation.

Phase	**Activities**
Pre-design	General guidelines: size of project, main HVAC services, information transmission and protection, physical possibilities, ways of maintenance.
Design	Detailed design: types of sensors (CO2, temperature, humidity, motion etc.), location, amount, accepted values and limits, alarms. Methods of tracking, data collection and limit, communication, installation plans. Selected data points and data connection for future EMS. Design drawings and descriptions. **Document 1: MBCx document (technical)**
Contracting	Definition of an acceptable frame, both technically and financially with HVAC and electrical engineers to possibly avoid significant future changes.
Construction	Verification of the components and the tender. Integration of design and components, build up the system and document the construction-based changes (as-built). Final version of maintenance documents, assurance of consumptions and processes living up to the design expectations. **Document 1.2: MBC update (as-built)** to be completed.
Operations and maintenance	Prioritized alarms, maintenance tickets, lists of critical operations, FDD controls, tests. **Document 2: Ongoing Commissioning Plan (operation)** and 10-month review (LEED), feedback resolution.

MBC activities start in an early design phase and keep changing during the entire procurement and implementation phase. The most important activities are permanent energy monitoring, real-time energy analysis and ongoing commissioning. To ensure the completion of all tasks in time, two reports and one update should be produced: a Monitoring Based Commissioning Plan, and an Ongoing Commissioning Plan.

Document 1: Monitoring Based Commissioning plan
The scope of the plan is to maximize the building performance in design and installation phase. It includes the core of system attributes, from installation and future operations point of view, therefore, detailed technical descriptions are to be avoided.

1. Roles and responsibilities ground the frame of the commissioning process, by defining the key tasks and performers, as it may be seen below:
    - A detailed list of the commissioned services systems which are controlled by the automation system and followed in the monitoring/energy management system.
    - Involvement of the responsible persons to complete the tasks.

2. Automation System Manual (BAS). Part of the BAS information is available as early as in the design phase but some become known only after the agreement with the automation contractor. The list below presents the information that is necessary to create a manual. The information should be retrieved as early as it is available:
    - A list of selected data points and the location of their sensors to track for EMS (ID, location, equipment/part with function).
    - Separate metering system description, if the metering data is indirectly linked to the automation (if applicable).
    - Valid ranges for tracked points and metering points measurements (default design value and allowed minimum-maximum values).
    - Alarm types with a short description of alerting cases and action plan for alarm resolution (notification / fault / error / fail).
    - Clearly identified metering points of water and energy consumption in the facility.

    Software-specific automation information is also needed for the manual. However, in practice it becomes available known only after selecting the vendor. The list below introduces the mandatory data:
    - Review on the software, communication and system architecture.
    - System reset option description.
    - Fault detection and resolution tool and suitability to the automation system.

  - Data transfer method internally and externally (network / protocol type).
  - Remote access provision (levels and rights).

3. Energy Management System (EMS): the specific information becomes available from the contract about the selected system, therefore it can be only known in later phases. The typical information that is needed is listed below:
   - Software/cloud service description.
   - Remote data transfer and storage description.
   - Remote access provision.
   - Suitability with the BAS.
   - Trend and report creation possibility.

4. Monitoring principles or requirements: they may be defined already in the design phase. Additional, concrete information becomes available and changes may occur during contracting, as the systems are chosen and their specifications become decisive. Typical information that needs to be retrieved to the commissioning plan includes the following:
   - Frequencies of measurement according to the service (minute, hour, day).
   - Form of remote data transfer and storage possibilities.

5. Definition of the first year's performance-evaluating elements during design phase, to be adjusted and modified after construction phase. The list below introduces a few examples regarding the evaluating elements:
   - Resolution of one-time system conflicts (e.g. simultaneous heating and cooling, extended occupancy schedules) expected during the first year
   - Out-of-sequence operation of system components: recognition and reaction (resetting possibilities in the building automation system).
   - Unusual usage profiles recognition: upper limits and duration of extraordinary consumption data.
   - Verification of ventilation flow rates testing results and necessary automation adjustments accordingly.

6. A plan of maintenance staff training for operation and maintenance phase, on principle level must be developed during design phase. Changes will automatically occur in contracting phase as the manufacturers' own instructions become available.

The following list underlines the most practical attributes to consider when preparing a staff training:

- The assigned staff must be familiar with the installed systems, roles, operation conditions, alarms and physical alarm resolution.
- Building management will be concluded through a cloud service vendor. The actual vendor may be selected in the contracting phase.
- An online space will be dedicated for future documentation:
    - A collection of Systems Manual documents (huoltokirja) delivery to the cloud system.
    - Work schedule about daily/weekly/monthly tasks, replacement.
    - Reports about the results of tests concluded in the facility.
    - Relevant design documents.
- Planned, scheduled education on the locally installed building management system.
- Error-preventing training for the maintenance and for the occupants – different types of alarms and education on acting in alerting cases, based on the design values defined in automation.

7. Definition of Ongoing Commissioning principles: monitoring scheduling (minimum 4 times/year) and measurement plan for operation and maintenance phase. The measurement process is more limited than at the previous stages. However, it must include key elements, which may be as follows:
    - Data comparison between simulated baseline and measurement.
    - In case large differences are detected, an action plan to conduct changes.
    - The definition of what exactly to look for in the installed EMS (a list of attributes, consumptions)
    - Reaction to implement when an acute case occurs (e.g. extreme consumption)
    - A defined control of measurement calibration (testing method description), utilization of manufacturers' recommendation, when available.

Document 1.2. is the implementation report, or in other words the MBC update. As in detail design phase the documents often change, frequent updating of the created design works is the interest of the entire stakeholder's group. To ensure the delivery of this document, the LEED Guide announces frequent updates and then the submittal of the final MBC document. The final version of the plan will serve as the grounding material for systems manual. (28, p388). The following list was created during development sessions at GBP (36). The expected content of an update is as it follows:

1. A list of completed commissioning regarding the systems and monitoring tasks (366).
    - A relevant change, if there is any.
    - A description how EMS, components, devices are installed and tested.
    - A verification on the creation and delivery of all System Manuals documents (huoltokirja).
2. Approved suitability with the EMS / online monitoring system, attested connection and data acquisition from the field equipment to the online monitoring system.
3. A detailed description of functional test methods (test scripts) from construction phase and their results.
4. A verification about the fault diagnostics ability of the software.
5. A verification about the training provided to the facility maintenance person.
6. A decision that the technical processes are followed by another competent person (energy manager).

Document 2: Ongoing Commissioning plan

The scope of this document is to maintain the designed and achieved building performance as well as to map possible means of optimization. The Ongoing plan is a natural continuation of the Monitoring plan, it is based on the preceding design and features of the project building. (28.)

1. Roles and responsibilities will define the frame of maintenance and will include the following ones:
    - Involvement of an appointed facility manager (FM), energy manager (EM) and facility services provider (FS).
    - A task list about ongoing commissioning systems, based on installation phase.

2. Reporting is the default form of communication between the facility's performance and management, therefore, it should be the frequent and include:
    - Energy consumption report in first year 4 times, later minimum annually.

- Frequent reporting on repair and usage optimization suggestions.

3. Field equipment maintenance includes a schedule of activities, recommendation of manufacturers of the installed machinery, and frequencies, as it is listed below:
   - Consumption readings for analysis done and registered monthly to the online monitoring system. This activity is automated.
   - Calibration and replacement of the sensors (according to manufacturer's recommendation as it becomes available).
   - Field equipment and automation system monitoring (deficiency identification and energy saving measurement) for a 24-month cycle.
   - For larger sites, sampling: minimum 10 sample points or 10% of the equipment –according to the greater one.
   - Seasonal (2 times/year) HVAC testing according to prepared scripts – US practice. In countries where BAS is an implicit installation, such as in Finland, testing is not necessary, since the automation system is based on constant ongoing testing (programmed logic).

4. To highlight and utilize the true potential of an energy monitoring system, the facility management should frequently report on improvement possibilities, implementation and verification, including the following ones:
   - Energy saving measures and energy efficiency monitoring (including data collection and storage).
   - Issues log on problematic devices and controls, user requests and automation alarms.

To test the financial effectiveness and adaptivity of building automation control and to complete LEED requirements, GBP has conducted a case study about the verification and post-occupancy evaluation of a shopping center at a recently opened metro station.

The Finnish capital area has procured and started operating some new metro stations both in Helsinki and Espoo. All construction sites were large both in size and budget, some of them involving new buildings, such as offices and shopping malls. Green Building Partners took part in the energy design of the project, including monitoring-based commissioning. GBP designed the building energy baseline using the Riuska simulation software. Access was provided to follow the operating automation system and download consumption data.

As the initial one-year period of operation phase expired in the end of 2017, the consumption data that had accumulated was ready to be read and used as the base for comparison with the simulation model.

The facility has a separate sub-metering system, installed between the field equipment and the automation control, because it is large in size and has complex systems. Data about energy and water consumption were available online, in downloadable Excel sheets. However, the connection between the electricity meters and the field equipment, such as ventilation machines was not always linked in the automation drawings, which made the device-specific consumption identification rather time-consuming. Other HVAC and energy-related data was collected from the online application. For the verification and POE, data was paired with the equipment usage and fed back to the original simulation model, to calibrate the model. The main changes included temperature data adjustment, occupancy schedules updates, pressure relations, specific fan power (SFP) classes and load extents, such as light load. The model was then run with the updated dataset, to approach the proven consumption data. According to the first calculation result, some of the systems of the facility sometimes exceeded, but also lagged behind the expectations, which then gave an excellent opportunity to review the settings and propose potential cost savings and device repair service possibilities for next year's automation control and maintenance plan. After running multiple setting scenarios, the new results have highlighted concrete numeric suggestions. In several spots the consumption can be optimized by setting a lower temperature, by eliminating simultaneous heating and cooling, by optimizing the schedules and introducing further ventilation control possibilities to the end users. Maintenance of the rotating heat exchangers could greatly contribute to the efficiency and, therefore, to further savings. In the automation system, some of the control valve signals and operation has shown discrepancies: e.g. showing cooling load although the cooling valve appeared to be 100% closed; unexpected temperature differences inside the equipment; worse heat exchanger efficiencies than in reality, according to a different applied calculation method. Table 3. introduces the total of possible savings.

Table 3. Improved consumption saving potential.

Service	**Consumption (MWh)**	**Improved consumption (MWh)**	**Savings (€)**
Electricity	846	824	
Cooling	373	353	
Heating	2.727	2.322	
Total	3.946	3.499	22.730

This case study proves how the specific input data shapes and influences the design baseline; the importance of proper settings in the automation; the effect of frequent measurement and the true cost-saving potential of the monitoring-based commissioning.

6 Future Development Possibilities and Discussion

Permanent monitoring and real-time analysis are relatively new forms of energy performance evaluation. LEED and other guides also suggest significant steps to complete the evaluation, in order to verify and constantly develop the building. However, due to practical immaturity, the expectation is hard to live up to. In this chapter, the main deficiencies and faults are listed to accentuate the most important areas of future development. Despite the recognition of the importance of monitoring, measurement and verification, there is no commonly used standard for MBC. In practice, there are no clear instructions on the BAS and EMS documentation to provide for the LEED project managers. LEED in version nr 4 has launched an extended approach on the commissioning process however it does not give a clear instruction on the required technical details. When a company has no clear practice on a new process, it is hard to evaluate whether the depth/extent of provided information is satisfactory.

Some processes and technical specifications need further research and practice in the industry. A major deficiency is the difficulty of information gathering. It can be seen in the plan presented in Chapter 5 as well. Much of the necessary data is available in early stages of the procurement, but the delivery of that data wakes further questions. Many of the completed tasks by e.g. automation designers are not documented in the current procurement practice.

The calibration of various components and stages is currently in its infancy. Human load calculation in simulations is based on static, predicted load profiles. The Random Walk model theory from 2017 (55) has proven the validity of a more dynamic approach to user load modeling in simulation applications. The development of new algorithms needs capital investment and also time for the researchers. Additionally, implementation to the simulations will also cause further difficulties.

Alarms are considered a rather complicated and problematic part of automation systems. New, more adaptive, calibrated algorithms could contribute to create fewer but truly valid alarm signals, and thus lessen human interaction associated with alarms.

The lack of a standard of communication between automation systems and energy management systems has created a product variety on the market, yet imposed a limitation when choosing an EMS service for the designed BAS. This leads at least to configuration problems, database access issues, information protection concern between internal and external data flow.

The lack of a regulated commissioning process also causes design differences in the metering strategy. Larger project facilities may complete metering activity indirectly, but this information is vital to receive in an early design phase. The consequence is the possible replacement of an existing installation.

There is a great amount of data produced from building automation and energy management systems. There are ready, developed analyzing tools to utilize the data. Also, data storage, data access from inside and outside of BAS and visualization are common possibilities. However, creating trends in these days is a critical issue. The reason behind is the missing training on trend creation. This leads to potential possibilities of performance development.

7 Conclusion

Monitoring based commissioning activities serve as a quality assurance tool to verify the true consumption data of a building and develop them if applicable or necessary. As MBC comprises several scientific fields, varying from building physics through energy engineering to modeling and programming, the commissioning process must reflect this complexity as well. By the multilayered structure of the tool it is possible to see how the operating building energy processes are set up and how they can be manipulated through the automation and energy management system. The final scope of monitoring is the achievement of high energy efficiency and long-term high performing sustainable buildings.

A properly detailed commissioning process gives an excellent possibility for all involved design and executive parties to communicate and notify all team members about every change and option to resolve.

As the MBC verification tool is so new in the Finnish green building industry, there is no clear public project submittal so far that has completed monitoring based commissioning. This present situation imposes great difficulties for any project company that is committed to continuous monitoring. However, the true advantage of this assurance tool is self-explanatory.

To complete successful verification processes, it is vital to be connected with the project not only at the design phase but continuously, during the entire operation phase. LEED gives pithy instructions to establish regular reviews of the project buildings. Based on the findings, it is undeniable that building energy optimization is an active, laborious field that needs further research and investment from scientific and commercial parties. Just as commissioning has many possibilities to offer, also the chance of risk to mistake is significant. Therefore, verification and continuous commissioning is a challenging, comprehensive, yet professionally fulfilling and inspiring task. Most likely it will become a fundamental process to promote both new and renovation project green buildings toward intelligent buildings.

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