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Non-domestic building typologies

Systematic selection criteria for case studies for improved energy efficiency in management and use

Master's thesis in Real Estate and Facilities Management

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Ekstrakt:

This master's thesis highlights the importance of management and use in relation to energy efficiency in existing non-domestic buildings. The purpose of the master's thesis is to study the energy efficiency of existing non-domestic buildings through a focus on the gap between expected and actual energy use and management and use. The aim is to contribute to close the gap between expected and actual energy use in existing non-domestic buildings, while providing knowledge of management and use of such buildings.

The master's thesis study Realfagbygget (university and college building) and Miljøbygget (office building) in a case study to examine how expected energy use is calculated, how energy use is measured and factors that impact energy use – especially in terms of management and use of the buildings. The two buildings was selected through a systematic selection method. There has been conducted interviews to support the case study. Both the case study and the interviews has been conducted in Trondheim. The gap between expected and actual energy use is presented for the two buildings with possible causes and solutions. There has been conducted a literature study to collect and form a foundation of relevant theory and literature. The literature study and the case study is analysed to answer a thesis question which is supported by three research questions.

The master's thesis shows that there is a gap between expected and actual energy use for the two existing non-domestic buildings in the case study. This is related to how the expected energy use is calculated, which is based on historical figures of actual energy use. Actual energy use is measured with energy monitoring devices which communicate the energy data to a building management system and a energy monitoring system. There are several impact factors that affect the actual energy use which is both related the facilities management of the buildings, the users, their user behavior and user patterns, but also other factors. There is presented several barriers against energy efficiency, but also approaches to energy efficiency such as energy management, monitoring, visibility and communication across the organizations, among others. The gap, with related causes and solutions is based on this and is consistent with the conclusion. Since the impact on actual energy use depend on various factors that are associated with varying uncertainties to what extent the factors will affect each specific year, it can be concluded that there always will be some degree of uncertainty to the expected and actual energy use, that will result in some degree of gap.

Stikkord:

1. Existing non-domestic buildings
2. Energy efficiency
3. Facilities management
4. User behavior

(sign.)

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NTNU

Fakultet for arkitektur og billedkunst

MASTEROPPGAVE I STUDIEPROGRAMMET MASTER I EIENDOMSUTVIKLING OG FORVALTNING

for

Masterstudent	Daniel Romsaas Hansen & Lars Arne Kimo Jørgensen
Fagområde	**Eiendomsutvikling og forvaltning**
Utleveringsdato	**10.01.2014**
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Tittel oppgave	**Non-domestic building typologies – Systematic selection criteria for case studies for improved energy efficiency in management and use** Kommersielle bygningstyper – Systematiske utvalgskriterier for casestudier for økt energieffektivitet i forvaltning og bruk
Formål	Å undersøke energieffektiviteten til eksisterende ikke-beboer (non-domestic) bygg gjennom et fokus på gapet mellom forventet og faktisk energibruk og forvaltning og bruk.

Følgende hovedpunkter skal behandles;

1. Identifisere og utvikle utvalgskriterier til en systematisk utvalgsmetode for utvalg av representative caser av eksisterende ikke-beboer bygg og benytte denne for å velge ut bygg til en casestudie.

2. Gjennomføre casestudie av utvalgte eksisterende ikke-beboer bygg der hovedmomentene i casestudien er beregning, overvåkning og påvirkning av energibruk.

3. Analysere, sammenligne og presentere resultater og funn.

…………………………………………	…………………………………………
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Abstract

This master's thesis highlights the importance of management and use in relation to energy efficiency in existing non-domestic buildings. The purpose of the master's thesis is to study the energy efficiency of existing non-domestic buildings through a focus on the gap between expected and actual energy use and management and use. The aim is to contribute to close the gap between expected and actual energy use in existing non-domestic buildings, while providing knowledge of management and use of such buildings. This can contribute to a more stable energy management and energy efficiency in existing non-domestic buildings.

The master's thesis is designed as a case study of two different non-domestic buildings that has been selected through criteria in a systematic selection method. The selected buildings are Realfagbygget (university and college building) and Miljøbygget (office building), which is located in Trondheim. The case study is supported by 12 interviews of managers and users of the buildings. There have also been conducted a literature study to gather a foundation of relevant theory and literature. The master's thesis have the following thesis question; How to reduce a gap between expected and actual energy use in existing non-domestic buildings? This thesis question is supported by three research questions. The first research question is; How is expected energy use calculated in existing non-domestic buildings? The second research question is; What factors affect energy use i existing non-domestic buildings? The third research question is; How does the management and use affect the energy efficiency in existing non-domestic buildings? Both the thesis question and research questions are answered through the analysis of the master's thesis.

The master's thesis shows that there is a gap between expected and actual energy use for the two existing non-domestic buildings in the case study. This gap varies from year to year and is based on how the expected energy use is calculated. The calculation methods of the two buildings in the case study has both similarities and differences. Both methods are based on historical data of the actual energy use in the two buildings. Actual energy use is measured with energy monitoring devices that communicate energy data to a building management system and an energy monitoring system. There are several factors that affect energy use, which can be related to the management and operation, users with different user behavior and patterns, as well as other factors such as the building itself and the outdoor temperature among others. There are presented various barriers against energy effiiency, as well as multiple approaches towards energy efficiency. Examples include energy management, good monitoring of buildings, better visibility and communication across organizations in the building, among others. The gap between expected and actual energy use has different causes and solutions and it can be concluded that there always will be some degree of uncertainty to the expected and actual energy use, that will result in some degree of a gap.

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Sammendrag

Denne masteroppgaven belyser viktigheten av forvaltning og bruk i forhold til energieffektivisering av eksisterende ikke-beboer bygg - ofte kalt kommersielle- eller yrkesbygg. Formålet med oppgaven er å undersøke energieffektiviteten til eksisterende ikke-beboer bygg gjennom et fokus på gapet mellom forventet og faktisk energibruk og forvaltning og bruk. Med dette ønsker vi å bidra til å tette gapet mellom forventet og faktisk energibruk for eksisterende ikke-beboer bygg og samtidig presentere kunnskap om forvaltning og bruk av denne typen bygg. Dette kan bidra til en mer stabil energistyring og energieffektivitet i eksisterende ikke-beboer bygg.

Masteroppgaven er formet som en casestudie av to ulike ikke-beboer bygg som ble valgt gjennom kriterier i en systematisk utvalgsmetode. De to valgte byggene er Realfagbygget (universitet- og høgskolebygg) og Miljøbygget (kontorbygg) som er lokalisert i Trondheim. Casestudien er støttet av 12 intervjuer av forvaltere og brukere av bygningene. Det også blitt gjennomført en literaturstudie for å samle inn å skape et fundament av relevant teori og literatur. Masteroppgaven har en problemstilling som lyder; Hvordan redusere et gap mellom forventet og faktisk energibruk i eksisterende ikke-beboer bygg? Denne problemstillingen er støttet av tre forskningsspørsmål, der det første er; Hvordan er forventet energibruk beregnet for eksisterende ikke-beboer bygg? Det andre er; Hvilke faktorer påvirker energibruk i eksisterende ikke-beboer bygg? Det tredje er; Hvordan påvirker forvaltning og bruk energieffektiviteten i eksisterende ikke-beboer bygg? Både problemstilling og støttende forskningsspørsmål blir besvart gjennom analysen i masteroppgaven.

Masteroppgaven viser at det er et gap mellom forventet og faktisk energibruk for de to eksisterende ikke-beboer byggene i casestudien. Dette gapet varierer fra år til år og tar utgangspunkt i hvordan forventet energibruk blir beregnet. Beregningsmetodene til de to bygningene i casestudien har både likheter og ulikheter. Begge metodene er basert på historiske tall av det faktiske energibruket i de to byggene. Faktisk energibruk blir målt med energimålere som kommuniserer energidata til et SD-anlegg og et energioppfølgingssystem. Det er flere faktorer som påvirker energibruket, som kan knyttes til forvaltning og drift, brukerne med ulik brukeratferd og -mønstre, samt andre faktorer som blant annet selve bygget og utendørstemperaturen. Det er presentert ulike barrierer mot energieffektivisering, samt flere metoder og tiltak for energieffektivisering. Eksempler på tiltak er blant annet energystyring, god overvåkning av bygg, bedre synlighet og kommunikasjon på tvers av organisasjoner i bygg. Gapet mellom forventet og faktisk energibruk har ulike årsaker og løsninger og det kan konkluderes med at det alltid vil være en viss grad av usikkerhet knyttet til forventet og faktisk energibruk som vil resultere i en form for gap.

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Preface

This master's thesis is the final work in the study of Real Estate and Facilities Management at the Norwegian University of Science and Technology in Trondheim. The subject code for the master's thesis is AAR 4992 and constitute 30 of the total 120 number of credits that the two-year master's program consists of.

The authors of this master's thesis are Lars Arne Kimo Jørgensen and Daniel Romsaas Hansen. Lars has previously taken a bachelor degree in engineering at Narvik University College (HIN) and has worked for four years as a project manager in the construction industry. Daniel has previously taken a bachelor degree in economics and administration with specialization in marketing and innovation at Sør-Trøndelag University College (HIST). Daniel has worked for two years in the banking and IT industry. This has been a great combination of expertise and background in regard to this master's thesis as building engineering and economics are two key disciplines within real estate and facilities management.

This master's thesis study energy efficiency in the management and use of existing non-domestic buildings through a focus on the gap between expected and actual energy use. This has been an exciting, challenging and educational process.

We would like to thank all the respondants who participated in the interviews - both users and managers. We would also like to thank the Operating department at NTNU, KLP Eiendom and Entro for their contribution and for helping us in finding or providing the relevant and needed data for our case study in regard to the two selected non-domestic buildings, Realfagbygget (university and college building) and Miljøbygget (office building), that met the criteria defined in a systematic selection method.

Finally, we would like to thank our mentor, Dr. Antje Junghans, for her time, help and contribution. Her guidance has been an important and decisive factor for how this master's thesis has developed.

Trondheim, June 2014

Lars Arne Kimo Jørgensen

Daniel Romsaas Hansen

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Table of contents

List of figures

List of tables

List of pictures

Attachments

Abbreviations

BMS - Building management system
DDF - Degree day figure
EMS - Energy monitoring system
GFA - Gross floor area
HR - Human resources
HSE - Health, safety and environment
HVAC - Heating, ventilation, and air conditioning
KPI - Key performance indicator
LCC - Life cycle costs
SLA - Service level agreement
TEK - Norwegian technical building regulation
UFA - Usable floor area (BRA - Bruksareal)

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Chapter 1

Introduction - an introduction to the master’s thesis

1.0 Introduction

1.1 Background

Within the Center for Real Estate and Facilities Management at NTNU there is focus on a new research project to develop methods for improving energy efficiency in non-domestic buildings. The aim of the research project is to close the gap between expected and actual energy use in non-domestic buildings and further contribute to improved energy performance in the building's lifecycle. We have chosen to use the term non-domestic buildings. Another similar term is non-residental buildings. Non-domestic buildings can be defined in different ways - we use the term for buildings that are not used for a residental purpose. Buildings such as schools, offices and hospitals are good examples of non-domestic buildings. These buildings belong to different building groups and types.

The Government of Norway has written three environmental action plans where the last one was applicable in the period of 2009 to 2012. These environmental action plans contains limits, priorities, objectives, requirements and measures for a more sustainable housing and construction sector with a reduced and environmentally friendly energy use and less climate gas emissions (Kommunal- og regionaldepartementet 2009). We are facing increasingly stringent building requirements to achieve more energy efficient buildings. In 2010, a revised building regulation (TEK 10) was implemented, which has stricter energy requirements for construction (Byggteknisk forskrift (TEK 10) 2010). The demand for energy efficient buildings rises. As a result, the construction industry face challenges to ensure that the expected energy estimated in the design phase becomes a reality in the operating and production phase (Menezes, Cripps, Bouchlaghem & Buswell 2011). According to Menezes et al. (2011) there is clear evidence that the buildings are not performing as expected and that it arises a gap between the expected and actual energy use. Some of the reasons for this are related to the use of unrealistic parameters in calculation models for buildings in relation to energy use, user behavior and management (Menezes et al. 2011). Since building requirements change over time, a different way to look at the gap between the expected and actual energy use is not to compare with the calculations from the design phase, but rather with the calculations done through out a buildings life cycle - year to year, month to month, week to week or even day to day.

Energy is necessary for the operation and use of buildings. Building related energy use accounts for about 40 percent of total energy use on average. Buildings are dependent on energy to function optimally and to meet the expectations of users. These expectations are in regard to temperature, air, lighting, elevators, information and communication technology solutions and more. It takes more and more power to keep the technical systems and solutions running (Junghans 2012). Junghans 2012 writes that innovations are needed to increase energy efficiency and improve infrastructure, operation and the usage of buildings. The goal is to use less and cleaner energy while ensuring the usability and functionality of the building (Junghans 2012). Junghans (2012) emphasizes that in order to achieve increased energy efficiency for buildings, new technological solutions is not the only answer. Improved knowledge of management and operation of buildings, as well as a focus on users' understanding and behavior is necessary (Junghans 2012).

Increased energy efficiency may be the result of a more realistic calculation of the expected energy use, forward-looking solutions in relation to current and future requirements for buildings and a greater focus on the proper use and management of buildings to ensure best practice. The gap between expected and actual energy use may be reduced - not only through more realistic calculations - but more importantly, through a greater understanding of how users will use the building and how the building can be managed according to best practice. This is what we want to investigate in our master's thesis, with a focus on the gap between expected and actual energy use through the life cycle of existing non-domestic buildings in relation with management and use. With this in mind, we began to write down any questions we had and wanted an answer to. How easy is it to predict how a building actually is used? Is the building managed optimally? What is best practice? How is expected energy use calculated through out the life of the building? How is it measured? What are the causes of the gap between expected and actual energy use? How can the gap be reduced? With the term gap we mean deviation. How is management and use related to this? These questions are the corner stone of our master's thesis and is reflected through our thesis question and associated research questions.

This master's thesis is our independent contribution to the research project within the Center for Real Estate and Facilities Management at NTNU - described on the previous page. We have studied two existing non-domestic buildings, Realfagbygget (university and college building) and Miljøbygget (office building), to investigate the various factors related to energy efficiency with a focus on the gap between expected and actual energy use, management and use. The master's thesis shall present relevant case studies and findings in combination with good theory and literature in order to highlight the factors in management and use that can cause gaps between expected and actual energy use for existing non-domestic buildings - and approaches for how it can be reduced. Knowledge and methods that can contribute to a reduction of the gap between expected and actual energy use can make it easier and more stable to manage buildings through a life cycle. At the same time, it may highlight the importance of both the management and use aspects for energy efficiency in existing non-domestic building.

1.1.1 Subject area

The subject area of the master's thesis is real estate and facilities management with a focus on the discipline of facilities management. To clarify, when we write management, we refer to facilities management. In section 2.5.1 it is explained that there are two ways of writing the term facilities management. We will use this term or 'management' in this master's thesis. The topic to be investigated is energy efficiency through management and use of existing non-domestic buildings with a focus on the gap between expected and actual energy use.

1.2 Thesis question

We have chosen a thesis question based on a demand for more energy efficient buildings and allegations of a gap between expected and actual energy use, focusing on the gap for existing non-domestic buildings and how this relate to management and use of the buildings to improve energy efficiency. The thesis question is also selected on the basis of the research project presented in section 1.1. Ertsaas (2013) has written a master's thesis in which she discusses the evaluation of energy use in passive house student apartments by focusing on a comparison between the calculated expected energy use in the design phase and the actual energy use in the operational phase. Ertsaas (2013) writes that the total energy use on average is about 60 percent above the calculated level. She linked this to the users (residents) and their impact on energy use. In contrast to buildings with purposes of housing and a focus on the gap between calculations of expected energy use from the design phase and actual energy use, we want a different approach and will investigate two existing non-domestic buildings - buildings in an operation and use phase - and the gap between expected and actual energy use in this phase. On this basis we have formulated the following thesis question:

Thesis question:
How to reduce a gap between expected and actual energy use in existing non-domestic buildings?

This thesis question aims to investigate causes of gaps between expected and actual energy use in existing non-domestic buildings. Is the gap caused by unrealistic expectations from the calculation of expected energy use through the buildings life cycle, is the gap a result of improper use and management of the building, and how can existing non-domestic buildings improve energy efficiency? A more realistic and accurate calculation of expected energy use and proper management and use may help to reduce the gap between expected and actual energy use through out the life cycle of the building. A study of the causes and information associated with this thesis question may contribute to knowledge towards a more stable energy management of existing non-domestic buildings through more a realistic and accurate calculation of energy use and possibly increased energy efficiency through reduced energy use due to greater understanding of management and use.

1.2.1 Research questions

We have formulated and selected three research questions to support, limit and answer the thesis question of our master's thesis. The three research questions focus on different aspects to highlight important factors in regard to the presented thesis question. The three research questions are presented below.

> **Research question 1:**
> *How is expected energy use calculated for existing non-domestic buildings?*

The first research question is a basic and important question to ask because we have to know how the calculation of expected energy usage through the existing non-domestic buildings life cycle is preformed. This will partly involve examining how the calculation is performed and on which basis, who performs the calculation, when the calculation is carried out, which parameters or data that are used and how the calculation for some non-domestic buildings may look like.

> **Research question 2:**
> *What factors affect energy use in existing non-domestic buildings?*

The second research question is aimed at monitoring and measurement of energy use. What factors influence energy use and to what extent. By collecting different numbers and factors we will be able to see if there is an actual gap between expected and actual energy use through out the buildings life cycle. If the building has been in operation and usage for several years, historical data on energy use will be helpfull for a better overview.

> **Research question 3:**
> *How does the management and use affect the energy efficiency in existing non-domestic buildings?*

The third research question aims to investigate, if possible, how the building was originally planned managed and used and how the building is managed and used today. Has there been any changes? Has the building improved the energy efficiency in it's lifecycle? Is the building managed and used optimally or is there large discrepancies leading to higher energy use in different areas? What areas and circumstances are we talking about and what connections can be drawn towards the two other research questions? What might be the causes and how is it related to management and use of the building?

1.2.2 Different subtasks

This master's thesis is conducted by five different subtasks. The subtasks briefly explains the agenda and the order of what to be done. Subtasks and research method are described further and more detailed in chapter 3.

Subtask 1 - Literature study:

Literature study and review of important and relevant literature about building types, requirements, standards and laws, calculation models, monitoring and measurement of energy use, management and operation (facilities management), energy efficiency, barriers against energy efficiency and user behavior in non-domestic buildings.

Subtask 2 - Systematic selection method:

Identify and develop selection criteria for a systematic selection method for the selection of two representative case studies of existing non-domestic buildings.

Subtask 3 - Select buildings for case study:

Use the systematic selection method on non-domestic buildings in Norway, specifically in the city of Trondheim. Discuss the benefits and risks with the selections. The selection shall consist of two different existing non-domestic buildings.

Subtask 4 - Conduct case study:

Conduct case study of the two selected existing non-domestic buildings. This include gathering necessary data, interviewing key respondents (facilities managers and users), visit the buildings, taking pictures, documenting and so on.

Subtask 5 - Present findings, analyze and compare:

Present the results and findings, analyse and compare.

1.3 Scope and limitation

This master's thesis is the basis for evaluation of the course AAR4992 - Master's thesis in Real Estate and Facilities Management at the Norwegian University of Science and Technology in Trondheim, accounting for 30 of the 120 number of credits. The master's thesis is to be written in a 20-week period from the 10th of january to the 11th of june. The master's thesis is written by two people - presented in the preface.

As mentioned, we want to investigate the energy efficiency of existing non-domestic buildings through a focus on the gap between expected and actual energy use and management and use. The gap between expected and actual energy use is not focused on the gap between the calculations done in the design phase, but rather the calculations or measures done through out the buildings life cycle, from year to year or even more detailed - hence 'existing' non domestic buildings. If, it is possible to find the background for and the calculations of the expected energy use from the design phase this would be a good starting point, but we have experienced that it is harder to find relevant data on this for older buildings, both because requirements for the construction and requirements for energy has evolved and gotten stricter over time. As a result, our focus in rather on the gap between the expected and actual energy use throughout the existing non-domestic buildings life cycle and how this is related to management and use of the building. The thesis question and research questions reflect the limitation of the master's thesis.

We have conducted a literature study to find relevant literature and theory to support the master's thesis. The result of the literature study will limit the master's thesis in some degree based on the expectations we produce as a result of it and because the theory and literature is a part of the analysis, which intends to answer the research questions and thesis question and is the basis of the conclusion.

In section 3.3.2, we present selection criteria for a systematic selection method which defines and limit the master's thesis further through criteria for the selection of two non-domestic buildings for the case studies to be conducted. The gap between expected and actual energy use is most likely easiest to illustrate for newer buildings because of more relevant requirements, implemented technology and data readings. We therefore feel that it is appropriate to set a criteria in regard to the age of the buildings to be selected. The criteria of age should not be too old (maximum 15 years old), but not too new either (minimum two years old). The two selected existing non-domestic buildings for our case study - shall be located in the city of Trondheim. This means buildings which are built according to Norwegian laws, standards and requirements. We will look at larger buildings which has a usable floor space (UFA) greater than 3000 m^2. These buildings must have a working building management system (BMS) which have worked in the building's life cycle. If the buildings shall be relevant to us there must be a gap between expected and actual energy use, whether the gap is positive or negative is not that important, but it would be interesting to investigate buildings that has both. In general we want to investigate rather new, medium-sized to large buildings which are good on paper with the necessary technology implemented such as BMS and energy monitoring system (EMS). There must also be users connected to the building and managers (or operators) who manages and operate the building. We will not go into great level of detail when it comes to construction, technical installations or different values and parameters in regard to calculations and standards. We have taken the liberty to translate some sitations and models to english from norwegian documents and literature, since they only has been available to us in norwegian. In this master's thesis it is the management and use that are focused on. The results are based on qualitative and quantitative data through data collection and study of documentation, reports, plans and interviews in a case study. In our selection for the case study, we have tryed to get two different building types, with different age to make the comparison more interesting in our thinking. The two selected buildings are Realfagbygget (over 14 years old), which is a university and college building and Miljøbygget (over four years old), which is an office building. These two existing non-domestic buildings not only have a difference in age, but also in regard to their requirements. We think this is an interesting selection of cases because of the different aspects available as a result of this. We think it is an important part of the investigation to see historical results as far back as possible to see if there is a positive or negative development for the gap between expected and actual energy use and energy efficiency of the two buildings in our selection. Since most buildings and related systems and installations are improved over the years of the buildings life, previous data might be lost because of the updates made. We should have in mind that management, operation and use usually have a break-in period - it takes time to find the optimal setup, tuning and procedures for the building. This break-ing period might take a year or two and even longer. This is also a difference in regard to the selected cases, where Realfagbygget has had a longer time to optimize and develop good management procedures, while Miljøbygget is a relatively new building in comparison.

To summarize, our master's thesis is limited in regard to the explained focus through the thesis question and research questions, through the selected theory and literature and through the two existing non-dometic buildings (the selected cases), which is selected through a set of criteria in a developed systematic selection method. We have also limited the master's thesis in regard to the level of details in construction, technical instalations and calculations. In figure 1 below is a simple overview of the master's thesis, from our starting point; the gap between expected

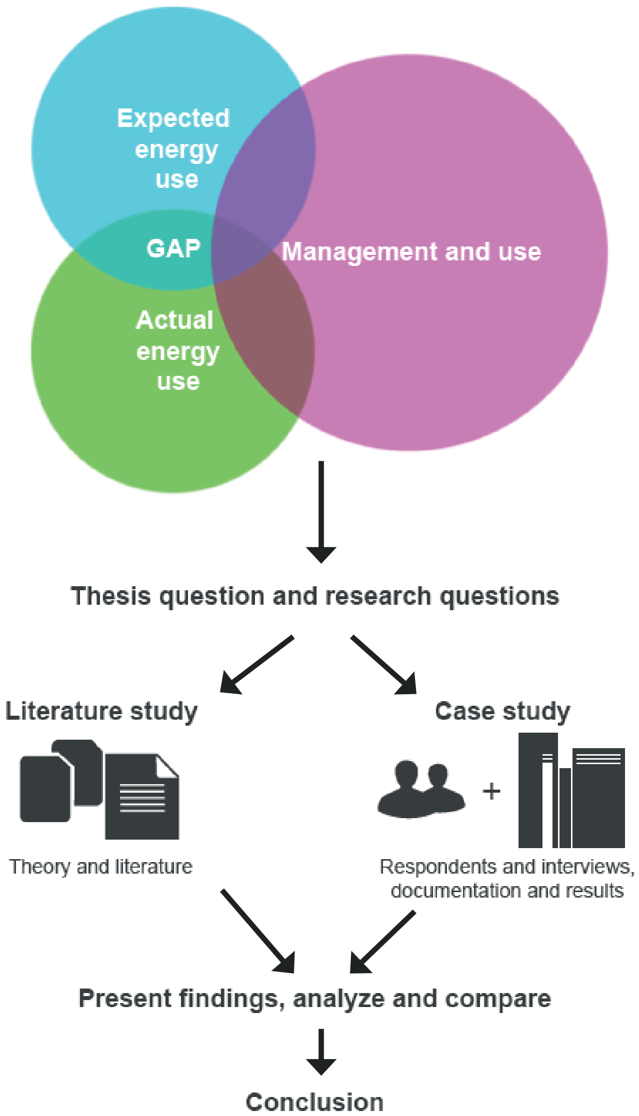

Figure 1 - Overview of the master's thesis.

and actual energy use in relation with management and use for existing non-domestic buildings and how we went from there by formulating a thesis question and research questions, and further through the selected and applied research methods and the structure of the master's thesis.

1.4 Structure of the master's thesis

The master's thesis is structured by main chapters with different subchapters or sections. Below is a brief presentation of the chapters and a description of the content.

1 - Introduction:

Introduction to the master's thesis which describes the background, subject area and discipline, thesis question, research questions, scope and limitations and the structure of this master's thesis.

2 - Theory and literature:

In chapter 2 we present the selected literature and theory foundation for the master's thesis. We have focused on presenting relevant literature and theory which is the result of a literature study that we have conducted. This chapter has a summary at the end to display a shorter overview of the chapter.

3 - Research method:

In chapter 3, we present an introduction to research methods. Further, we present the research method used for our master's thesis and study - how we intend to carry out our study and specific details in regard to this. Finally, we discuss the quality of research through two sub-sections about validity and reliability. This chapter has a summary at the end to display a shorter overview of the chapter.

4 - Presentation of cases and findings:

In this chapter, we present the two case studies and the findings from the case study and related interviews that we have conducted in this master's thesis. The cases was selected on the basis of a systematic selection method and criteria presented in chapter 3. We also discuss the benefits and risks in relation to the selected cases.

5 - Analysis and comparison:

In this chapter, we analyse the cases, findings and the theory and literature. We also make comparisons between different factors and findings in the two cases presented in chapter 4. This chapter intends to answer the research questions and the thesis question.

6 - Conclusion:

Finally, we will make a short and concise conclusion in regard to the research questions and the thesis question.

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Chapter 2

Theory and literature - a foundation of the master’s thesis

2.0 Theory and literature

In this chapter we present the theory and literature that the master's thesis builds on - the master's thesis theoretical foundation. This is knowledge and information that is collected by others and is called secondary data (Jacobsen 2005). The chapter aims to present central theory, knowledge, ideas and definitions that will form the basis for the analysis that we have presented in chapter 5, but will also support the rest of the master's thesis. Theory and literature has been selected on the basis of the research questions and to support the aspects of the master's thesis. We will begin by presenting theory about building types, energy requirements and calculation models. Furthermore, we will present theory of monitoring and measurement of energy use. Finally, we present theory about management towards best practice and user behavior in non-domestic buildings. We have written a summery at the end of the chapter to give a simple overview. We have adapted some sections towards the selected cases to make the chapter more concise.

2.1 Building types

The total building portfolio in Norway is very complex and consists of many building types of different age (NVE 2014). A standard has been developed for creating a common norwegian platform with definitions and systems for organizing information related to property and buildings (Standard Norge 2013). The standard is called NS 3457-3:2013. Figure 2 below shows how the system for classification of buildings are structured (Standard Norge 2013). The relationship between building part and rooms are clarified and there is also referred

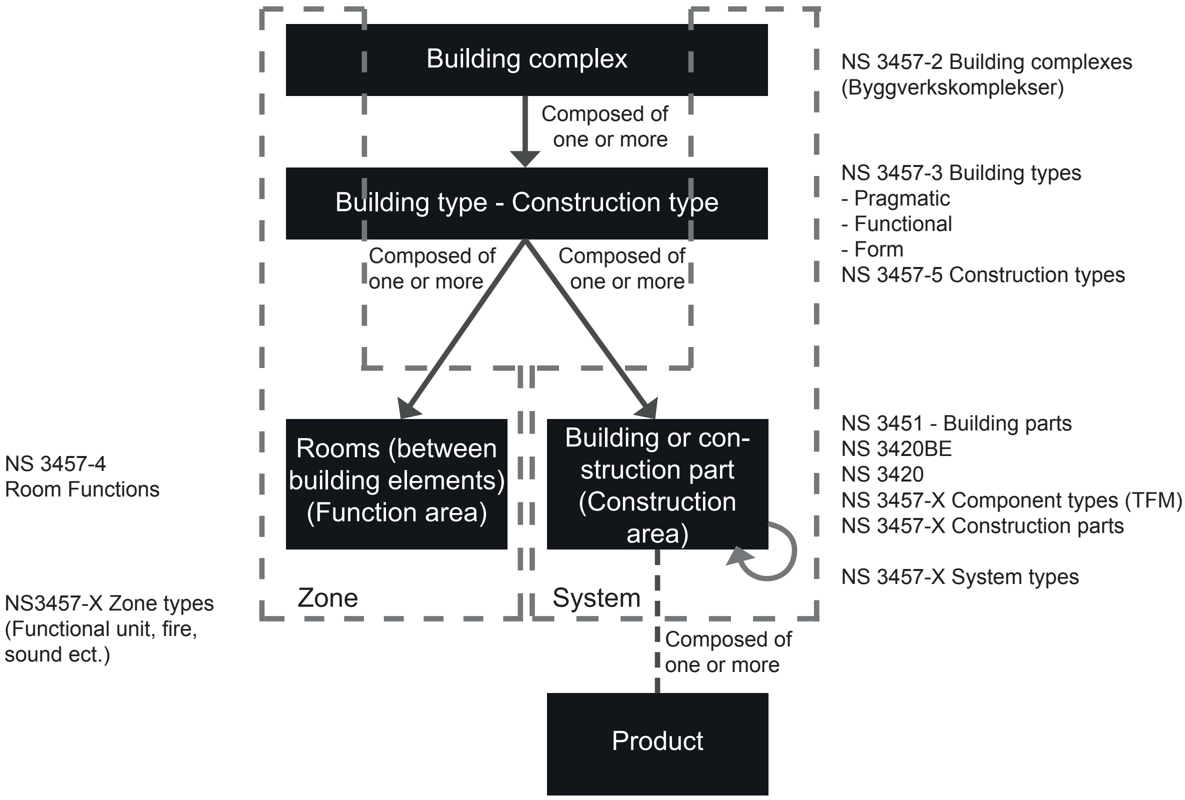

Figure 2 - Edited system for classification of buildings (Standard Norge 2013, p. 3).

to related tables and area types. The system is a collection of components or building parts that together complete a function. The zone on the other hand, is a collection of rooms, which both can be a logical grouping of rooms and a physical part of the building (Standard Norge 2013).

To classify a building type, it is important to know the building's function, since the classification of buildings is done based on this. Buildings shall be classified according to what the building are used for by the organization. It is not the industry that the organization operates in that define this. Buildings containing multiple functions under one roof is to be classified by the function that uses the greatest usable floor space (UFA). Area and volume calculations of buildings is carried out according to the standard NS 3940:2012 (Standard Norge 2013).

Classification of buildings is performed by three levels. The first is by the main function on a one-digit level, the second is by building group on a two-digit level and the third is by building type on a three-digit level (Standard Norge 2013).

Instead of presenting all the different building functions, groups and types, we decided to present those who where relevant in regard to the two selected non-domestic buildings for the case study in this master's thesis. There are two building main functions that are relevant for this master's thesis; main function 3 (office and commercial building) and main function 6 (educational, sporting and cultural building). The relevant building groups and related building types for these two building main functions is presented below (Standard Norge 2013). We have translated this from the norwegian standard NS 3457-3:2013.

The relevant building groups for building main function 3 (office and commercial building) is; 31 - office building (Standard Norge 2013).

The relevant building types for building group 31 (office building) is; 311 - office building (Standard Norge 2013).

The relevant building groups for building main function 6 (educational, sporting and cultural building) is; 62 - university and college building (Standard Norge 2013).

The relevant building types for building group 62 (university and college building) is; 621 - building with integrated functions, auditorium, reading room etc. (Standard Norge 2013).

All building main functions, building groups and building types is shown in the norwegian standard NS 3457-3:2013 (Standard Norge 2013).

According to NS 3457, a building is defined as a "[...] structure that has one of its main purposes to provide protection for those who stay there or the objects that is stored there, and is usually enclosed and intended to be permanently in a place" (our translation) (Standard Norge 2013, p. 4). A structure is defined as "[...] "anything that is built or is a result of construction work" (our translation) (Standard Norge 2013, p. 4) after the same standard.

2.2 Energy requirements

During the last 20 years, we have seen strictened energy requirements in technical regulations for new buildings. As a result, there is many who envisions a reduction in energy use in non-domestic buildings. Despite increasingly stringent energy requirements for new buildings, there is still some uncertanties in regard to how energy use will develop in the future. The uncertanties is particularly related to two factors - the relationship between expected energy use which is based on calculations and what the building actually use, that are based on measured values, and the uncertanty in regard to how the building area progesses and develop over time (Thema Consulting group 2012).

Even though the energy limits in the technical building regulation named Byggteknisk forskrift in norwegian has been reduced greatly over the years, the measured and predicted values do not always correspond with each other. There may be several reasons for the gap between calculated and measured energy use. Several interviews and quantitative comparisons indicate that newer buildings have more technical installations and systems that require optimal operation to function properly. There are also indications that building owners do not have the sufficient focus on the operating part in regard to management and operation of the building. New and advanced technical solutions increases the likelihood of possible errors, which will lead to an increased energy use for the building. There is in particular cooling and ventilation which use more energy than the estimated values (Thema Consulting group 2012).

How the total energy use will evolve in non-domestic buildings is dependent on the energy limits in future building regulations and to what extent the energy limits are complied with in regard to use of buildings, and the development of building area. As a result, a decline in energy use will depend on tightened energy limits and whether we are able to fulfill them in practice (Thema Consulting group 2012).

2.2.1 Current requirements

When a building is to be constructed you must follow the regulations and requirements of Byggteknisk forskrift. Byggteknisk forskrift is updated from time to time, regulate the quality of buildings and poses stricter requirements for buildings' energy demand, which shall ensure that new buildings are more energy efficient (NVE 2014).

As stated, there has been developed several technical building regulations named Byggteknisk forskrift in norwegian over the years, where the last was implemented from 2010, often called TEK 10 (Byggteknisk forskrift (TEK 10) 2010). Further described, this regulation is intended to ensure that buildings and measures are planned, that the building is designed and that the buildings are built in regard to visual quality, universal design, and that measures for technical requirements are set in relation to safety, health, environment and last, but not least, energy (Byggteknisk forskrift (TEK 10) 2010).

In terms of energy, TEK 10 § 14-1 (general requirements for energy), under the first and second sub-sections states that: ”(1) Buildings shall be designed and constructed so that low energy and environmentally energy supply is promoted. Energy requirements apply to the buildings’ heated usable floor space (UFA). (2) Calculations of buildings’ energy demand and heat loss figures shall be performed in accordance with Norsk Standard NS-3031:2007 Calculation of energy performance of buildings - Method and data. [...]” (our translation) (Byggteknisk forskrift (TEK 10) 2010, § 14-1). There is also a paragraph for energy efficiency under § 14-2, which under the first sub-section states that: ”(1) Buildings shall meet the level specified in § 14-3, or having a total net energy demand less than the energy limits specified in § 14-4. Minimum requirements in § 14-5 shall be met either § 14-3 or § 14-4 is used. [...]” (our translation) (Byggteknisk forskrift (TEK 10) 2010, § 14-2).

In regard to § 14-4 (energy limits) the total net energy demand for buildings shall not exceed the limits presented below (Byggteknisk forskrift (TEK 10) 2010, § 14-4). In multi-purpose buildings, the building shall be divided into zones based on building groups and the respective energy limits shall be met for each zone (Byggteknisk forskrift (TEK 10) 2010, § 14-4). The numbers presented below are total net energy demand (kWh/m² heated UFA per year) for the selected non-domestic building types in our case study (Byggteknisk forskrift (TEK 10) 2010, § 14-4):

Office building:	150
University/college building:	160

So, TEK 10 has two ways to meet the requirements of energy efficiency - the energy measures method in regard to § 14-3 and energy limit method in regard to § 14-4. In the energy measures method the building meet the energy reguirements by fulfilling a set of requirements for individual building parts and components. In the energy limit method the building meet the energy requirements by fulfilling requirements to the total net energy demand of the building. Whichever method that is chosen, the building has to fulfill a set of minimum U-values for building components and leakage rate in regard to § 14-5 (Lavenergiprogrammet 2014). We will get back to this in section 2.3.2.

2.2.2 Developments from former technical building regulations

There has been several developments in regard to energy efficiency the last 60 years. The technical building regulations (TEK 49 and TEK 87) from 1949 to 1987 lead to increased energy demand for several building types. The explanation for this was increased requirements for indoor air quality, particularly increased amount of ventilation air that had to be heated, which resulted in a higher energy demand. The technical building regulations (TEK 97) from 1997 had a much greater focus on reducing energy demand (NVE 2014). One of the biggest changes in the technical building regulation (TEK 07) from 2007 is the calculation methods and level of net energy demand (Hareide 2009). From 2015, it is expected new energy limits, which may be at approximately, passive house level (NVE 2014). This is also announced in a climate report from the norwegian ministry of environment (Miljøverndepartementet 2012).

Simulations with SIMIEN estimate the following developments of energy limits for total net specific energy demand per TEK-level - based on ideal conditions (Enova 2012a):

Office buildings (Enova 2012a):

- Older (kWh/m^2)	276
- TEK 49 (kWh/m^2)	271
- TEK 69 (kWh/m^2)	287
- TEK 87 (kWh/m^2)	250
- TEK 97 (kWh/m^2)	204
- TEK 07 (kWh/m^2)	167
- TEK 10 (kWh/m^2)	136
- Low-energy buildings (kWh/m^2)	101

University/college buildings (Enova 2012a):

- Older (kWh/m^2)	270
- TEK 49 (kWh/m^2)	255
- TEK 69 (kWh/m^2)	309
- TEK 87 (kWh/m^2)	273
- TEK 97 (kWh/m^2)	224
- TEK 07 (kWh/m^2)	181
- TEK 10 (kWh/m^2)	144
- Low-energy buildings (kWh/m^2)	105

For existing buildings, calculated specific delivered energy per TEK-level - based on more real conditions with additions for measures like operation and use (among others) give the following estimates (Enova 2012a):

Office buildings (Enova 2012a):

- Older (kWh/m^2)	311
- TEK 49 (kWh/m^2)	304
- TEK 69 (kWh/m^2)	308
- TEK 87 (kWh/m^2)	295
- TEK 97 (kWh/m^2)	218
- TEK 07 (kWh/m^2)	157
- TEK 10 (kWh/m^2)	114

University/college buildings (Enova 2012a):

- Older (kWh/m^2)	304
- TEK 49 (kWh/m^2)	286
- TEK 69 (kWh/m^2)	330
- TEK 87 (kWh/m^2)	320
- TEK 97 (kWh/m^2)	239
- TEK 07 (kWh/m^2)	169
- TEK 10 (kWh/m^2)	119

2.2.3 Low-energy buildings

Passive house buildings are buildings that use substantially less energy than the average buildings of today do. This is especially in regard to the heating factor of buildings. The measures that enable a reduced energy demand is better density in walls, floors and ceilings, extra insolation, better windows, the use of solar energy and re-use of heat from the ventilation systems (NVE 2014).

The norwegian standard NS 3701:2012 contains the criteria for passive houses and low energy buildings specified for non-domestic buildings (Standard Norge 2012).

The norwegian standard NS 3701:2012 has a practical use in regard to planning, construction and evaluation of non-domestic buildings which has a low energy demand. The standard has been written as a result of a demand for energy efficient buildings or rather buildings with a low energy demand. In regard to this it was necessary to develop a standard with definitions and requirements for this type of buildings (Standard Norge 2012).

For passive houses the total net energy demand (kWh / m² heated UFA per year) for office buildings and University/college building is (Boligenøk 2014):

Office building:	95
University/college building:	95

In comparison with TEK 10, this is a reduction of 37 percent for office buildings and a reduction of 41 percent for univeristy/college buildings (Boligenøk 2014).

Today, there is mostly office buildings that is constructed as passive house buildings, even though there is passive house buildings in all building groups. One factor for this is that office buildings - arguably - are easier to achieve as a passive house building. An other factor is that many organizations are keen to convey that they are concerned about the environment and want to take responsibility by using less energy (NVE 2014). NVE (2014) states that it is important for some organization to get energy label A, which almost corresponds with passive house level. We will get back to energy labeling in section 2.3.3.

2.2.4 Future requirements

As we have presented earlier - requirements may be an important factor for more energy efficient buildings. The norwegian government has announced that there will be new energy requirements from 2015 which will be on a passive house level. In this regard, there have been given tasks to depict potential energy regulations and requirements (Direktoratet for byggkvalitet 2013). Rambøll has proposed changes to TEK (technical building requlations) for new buildings (Rambøll 2013). In a report to Direktoratet for byggkvalitet (this is the norwegian directorate for construction quality), Rambøll suggest two alternatives changes to the technical regulations and requirements - in regard to energy efficiency (Rambøll 2013). The first alternative is a proposal to a simplified and more cost effective tightening of energy requirements in regard to cost optimization, and is much based on the current design of energy requirements. The changes are mainly directed to remove the energy measures method and that the new energy limits for different groups of non-domestic buildings should be reduced with around 40 percent. Suggested improvement areas are more efficient ventilation systems and measures to reduce air leaks, aswell as better controlling of lighting and ventilation, and also more energy efficient windows (Rambøll 2013).

The second alternative focus on to achieve the goal of passive house level where the most important changes are that the calculation point changes to delivered energy corrected for energy commodity and an implemented upper limit for heat loss figures. To change the calculation point may result in that good energy supply solutions are credited in regard to meet the requirements of the energy limits. This alternative will involve a stricter level of requirements since the changes will increase the flexibility to the calculation point in regard to techincal solutions (Rambøll 2013).

To sum up, Rambøll (2013) find it needed to simplify the requirement options to one instead of two - just the energy limit method. With just one method, the regulation is easier to follow, and may give an improved safety for a reducation in energy use (Rambøll 2013).

2.3 Calculation models

2.3.1 Calculation of energy performance

Calculation of energy performance can be done according to standard NS 3031:2007 (Standard Norge 2007b). The standard NS 3031:2007 is used to assess whether a building meets the energy requirements defined in the technical building regulations (TEK 10) that we presented in section 2.2.1 (Byggteknisk forskrift (TEK 10) 2010) and is also included in the calculations in regard to requirements to passive house buildings and low energy buildings through the norwegian standard NS 3701:2012 (Standard Norge 2012). The standard is also used to document the theoretical energy requirements, as well as to show a general level of existing buildings energy demand. The standard can be used to calculate alternative solutions to optimize energy performance and can assess measures to improve the energy performance of existing buildings (Standard Norge 2007b). This standard contains three different calculation methods where the first is monthly calculation (stationary method) done in regard to NS-EN ISO 13790, the second is simplified hour calculation (dynamic method) according to NS-EN ISO 13790, and the third is detailed calculation programs (dynamic method) which is validated according to NS-EN 15265 (Standard Norge 2007b).

The choice of calculation method shall be made based on the availability of data, appropriate detail, reproducibility in the calculation or accuracy (Standard Norge 2007b). NS 3031:2007 states that: ”The choice of calculation method will typically depend on how the current building is intended or used (categories of domestic or non-domestic buildings), complexity of the building and systems, if the building is new or existing and the purpose of the energy calculation” (our translation) (Standard Norge 2007b, p. 16). It is important to have in mind that calculations are done based on standardized parameters, values and data which may not translate to reality (Standard Norge 2007b). In figure 3 on the next page is an edited overview of the whole calculation procedure shown, which is presented in NS 3031:2007.

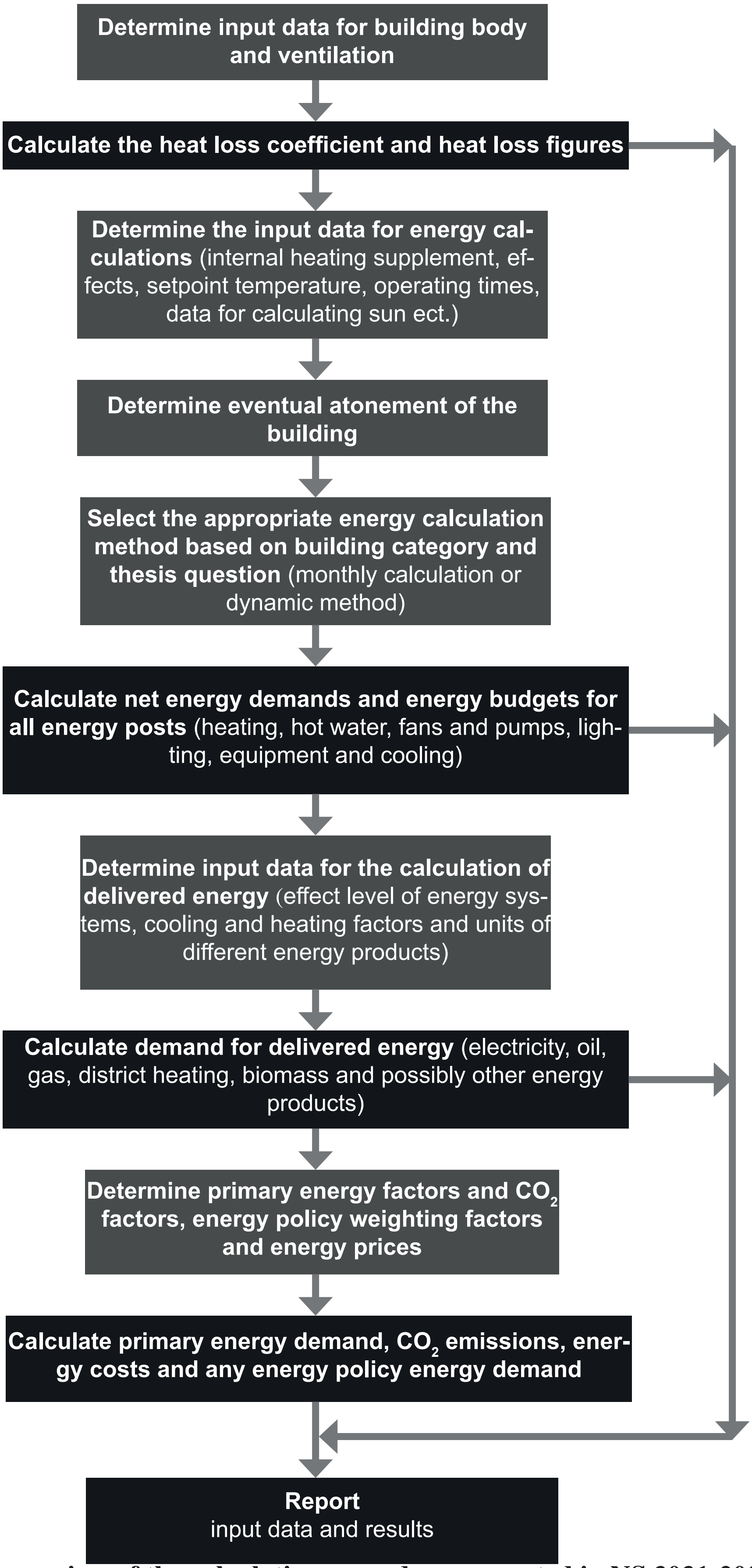

Figure 3 - Edited overview of the calculation procedure presented in NS 3031:2007 (Standard Norge 2007b, p. 5).

The calculations are made according to formulas, parameters, values and tables presented in NS 3031:2007 and in a range of other standards that are necessary (Standard Norge 2007b). We have translated figure 3 from norwegian to english - which make the figure an edited version of the one presented in NS 3031:2007 (Standard Norge 2007b, p. 5).

Energy demand is one of the calculation areas that are presented in NS 3031:2007 (Standard Norge 2007b). Energy demand are distinguished between theoretical and actual energy demand. The energy demand are individual for each building. Both energy use and performance is dependent on the energy demand and there is often a clear distinction between them (Hareide 2009). Energy demand is based on heating, lighting, fans and pumps, technical equipment, cooling of rooms, cooling coils, heat loss and heating supplement in regard to NS 3031:2007 (Standard Norge 2007b, Hareide 2009). The heating demand can be covered by different types of heat sources, which have different efficiencies to each. The remaining energy demand is for components which require electricity (Hareide 2009).

Theoretical energy demand is the net energy demand for buildings (Hareide 2009), and can be defined as the ”buildings total heat capacity divided by the heated part of the UFA” (our translation) (Standard Norge 2007b). Hareide (2009) writes that theoretical energy demand describes the properties of the body of building and how well the building utilizes passive supplementations. The teoretical energy demand (net energy demand) can be calculated, but not measured, which makes it an abstract concept (Hareide 2009). Net energy demand can also be described as the minimum amount of energy that is required by the buildings total energy posts when efficiencies of the energy system is equal to 100 percent - where the building properties depend on the materials, quality, technical qualities and proportion of window area (Hareide 2009).

Actual energy demand can be described as a buildings real energy demand since it is based on real energy use. The actual energy demand is calculated by multiplying measured or statistical values for the buildings energy use with system efficiency degree for heating and energy system in the building. In relation to the theoretical energy demand, the actual energy demand give a more accurate illustration of the building’s energy demand as it is calculated based on the real energy usage (Hareide 2009).

The discrepancy between theoretical and actual energy demand is primarily dependent on the buildings quality and the usage pattern. For non-domestic buildings, deviations occur because operating hours may be higher than the values given in NS 3031:2007. Heat loss that occurs due to material and construction errors is an other aspect that are not included in any calculation and may increase the discrepancy even further (Hareide 2009).

SINTEF Byggforsk has conducted interviews with different organizations and advisors in regard to use of calculation tools in the construction business. The main calculation tool used for energy calculations is SIMIEN, while others also use or supply with developed excel sheets. The calculation tools are used in relation with TEK, energy labeling, effect demand, and passive house standards. An interesting factor from the conducted interview is that there is little experience with actual energy use in contrast with calculated energy use, which is explained by that the advisors rearly follow up on the buildings while they're in an operation and use phase. Gaps between calculated energy use and actual energy use is explained with standarized input data which do not always translate to reality because of different usage behavior (Dokka, Svensson, Wigenstad, Andersen, Simonsen & berg 2011).

It is also discussed that there are different approaches to the use of NS 3031:2007 and that there is need for a more concise interpretation in regard to energy calculations and standards (Dokka et al. 2011).

2.3.2 Calculation of energy requirements

Calculation of energy requirements can in regard to the techinical building regulation (Byggteknisk forskrift, TEK 10) be performed by two different options, as described before. These two options are a energy limit method and a energy measures method. With the energy limit method there is given an energy limit for each building type. With standardized climate in Oslo as a starting point, there is made an estimate of the net energy demand according to standard NS 3031:2007. The result must be better than the energy limit for the building type (Dokka et al. 2011). With the energy measures method it is not required to make an energy calculation of the building. It is required to meet specified energy measures (requirements) given in the techinical building regulation (Byggteknisk forskrift, TEK 10) and thus one may assume that the regulation's energy requirements are met. You may redistribute within structural measures, provided that the building's heat loss numbers do not increase (Dokka et al. 2011).

2.3.3 Energy labeling system

A energy labeling system, Energimerkesystemet in norwegian, was implemented on the 1st of July 2010 and is mandatory. The responsibility for this system is assigned to Norges vassdrags- og energidirektorat, NVE (Dokka et al. 2011).

The energy label for buildings will be prepared based on the calculated supplied energy with standardized climate, as well as other standardized input and calculated according to standard NS 3031. There will also be a heating rating in the calculation, which indicates how high or low proportion of electricity and fossil fuels that is used for heating. The rating scale goes from A to G, where A is low energy use and G is high energy use. The aforementioned heating rating scale from light to red and indicates as stated before, the level from low to high proportion of electric heating and fossil fuels (Dokka et al. 2011).

Figure 4 below shows an edited model for energy labeling. This model is based on criteria of energy delivered per m^2 heated UFA (kWh/m^2) and proportion of electricity and fossil fuels.

In table 1 on the next page is an edited overview of the criteria for energy rating, which is edited from an original excel sheet (Energimerking 2013).

In table 2 on the next page is an edited overview of the related preconditions in regard to the criteria for energy rating (Energimerking 2013).

In table 3 on the next page is also an edited overview of the criteria for heating rating. The proportion of electricity and fossil fuels must be below the values given (percentages) in the table to achieve the color graduations (Energimerking 2013).

We have only shown the criteria for the building groups of office buildings and university and college buildings.

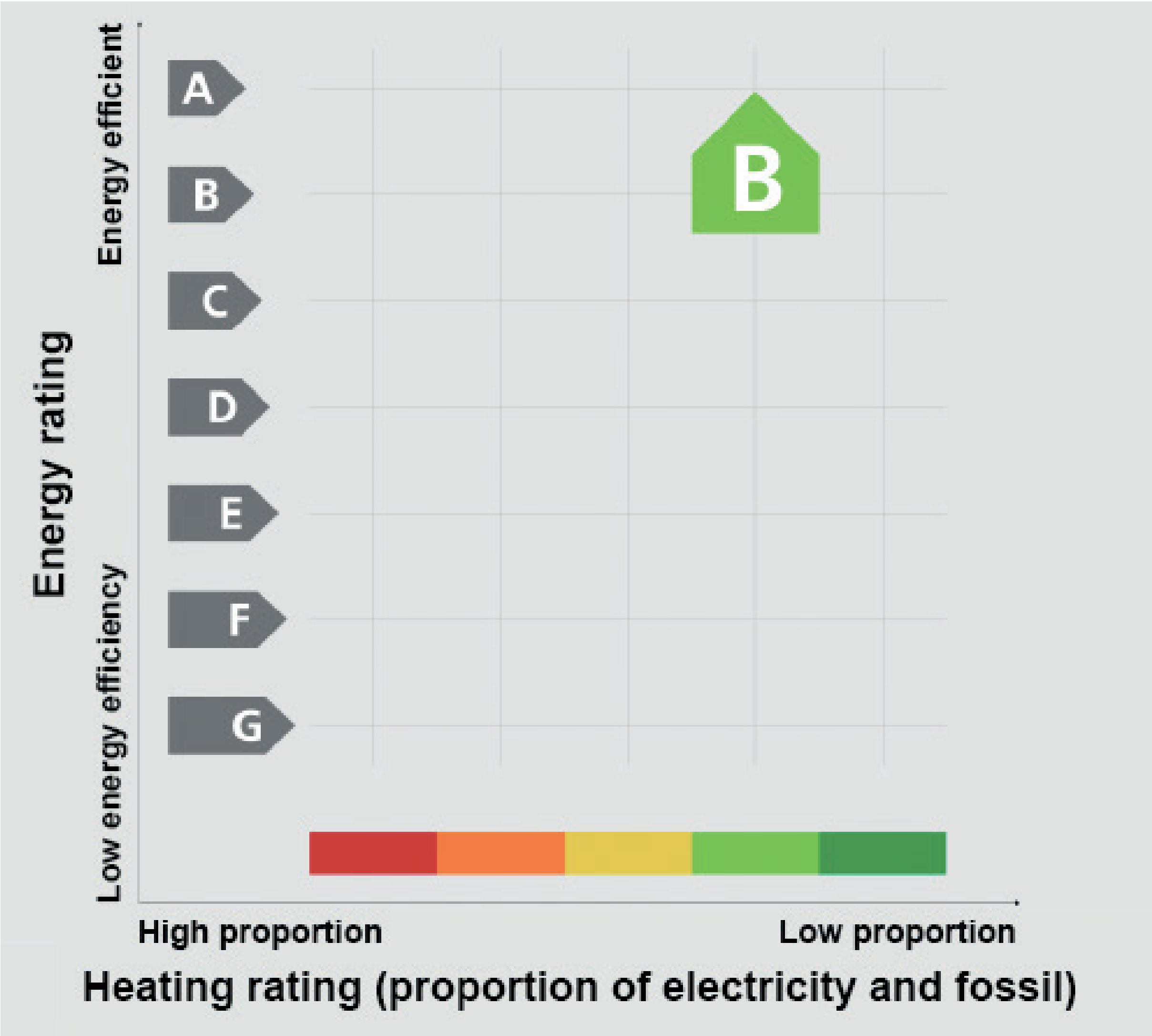

Figure 4 - Edited model for energy labeling (Energimerking 2011, p. 1).

Building groups	Energy delivered per m² heated UFA (kWh/m²)						
	A	B	C	D	E	F	G
	Lower than or equal	Lower than or equal	Lower than or equal	Lower than or equal	Lower than or equal	Lower than or equal	No limit
Office building	85,00	115,00	145,00	180,00	220,00	275,00	> F
University and college building	85,00	125,00	160,00	200,00	240,00	300,00	> F

A = heated part of the UFA [m²] *The upper limit for rating C is based on the level of TEK 2010.*

Table 1 - Edited table of criteria for energy rating (Energimerking 2013).

Preconditions	A	B	C	D	E	F	G
Upper limits	"Passiv hause"	(A+C)/2	"TEK10"	(2C+F)/3	(2F+C)/3	"TEK 69"+7%	> F
Reference	NS 3700 pr NS 3701		Heat recovery 80 %			Heat recovery 70 %	
Annual efficiency, heat	0,88	0,77					
Cooling factor	2,4	2,2					
Airflow in operation	NS 3031 tab A6	NS 3031 table B1					
Airflow outside the operation	NS 3031 tab A7	NS 3031 table A6					
SFP and lighting	Iht. prNS 3701 / NS 3700	in regard to NS 3031					
Equipment and hot water	Iht. NS 3031	in regard to NS 3031					
Movable shading	"On" throughout the year						
Building models	As TEK 2010						
Area correction	Level custom area correction for housing, depending on the scale steps.						
Calculating standard EMS	NS 3031:2007 / A1:2010						

Table 2 - Edited overview of related preconditions in regard to the criteria for energy rating (Energimerking 2013).

Heating rating				
▼				
30,0 %	47,5 %	65,0 %	82,5 %	100,0 %

Table 3 - Edited overview of the criteria for heating rating (Energimerking 2013).

2.4 Monitoring and measurement of energy use

Enova has developed an energy statistics where it was presented specific energy use for 2011 of different building groups (Enova 2014). Energy use is "[...] the use of all energy commodities" (our translation) (NVE 2014, p. 8). There are seven main groups of energy commodities. These are bioenergy, coal, district heating, electricity, gas, gasoline/diesel and oil - which are converted to kWh (NVE 2014).

Figure 5 below shows an edited overview of the energy use in 2011 - more spesific, a representation of average temperature and location corrected specific energy supplied for different building groups. We can see the proportion of energy that is used for the different building groups, as well as how large the total energy use is in kWh/m^2 which is temperature and location corrected supplied energy (Enova 2014). The office buildings used 215 kWh/m^2 and the university and college buidlings used 251 kWh/m^2. There was 293 office buidlings and 46 university and college buildings included in this statistics (Enova 2014). As we can see in figure 5, electricity is the main energy carrier for all the building groups, with exception for large residental buildings where also district heating is a main energy carrier (Enova 2014).

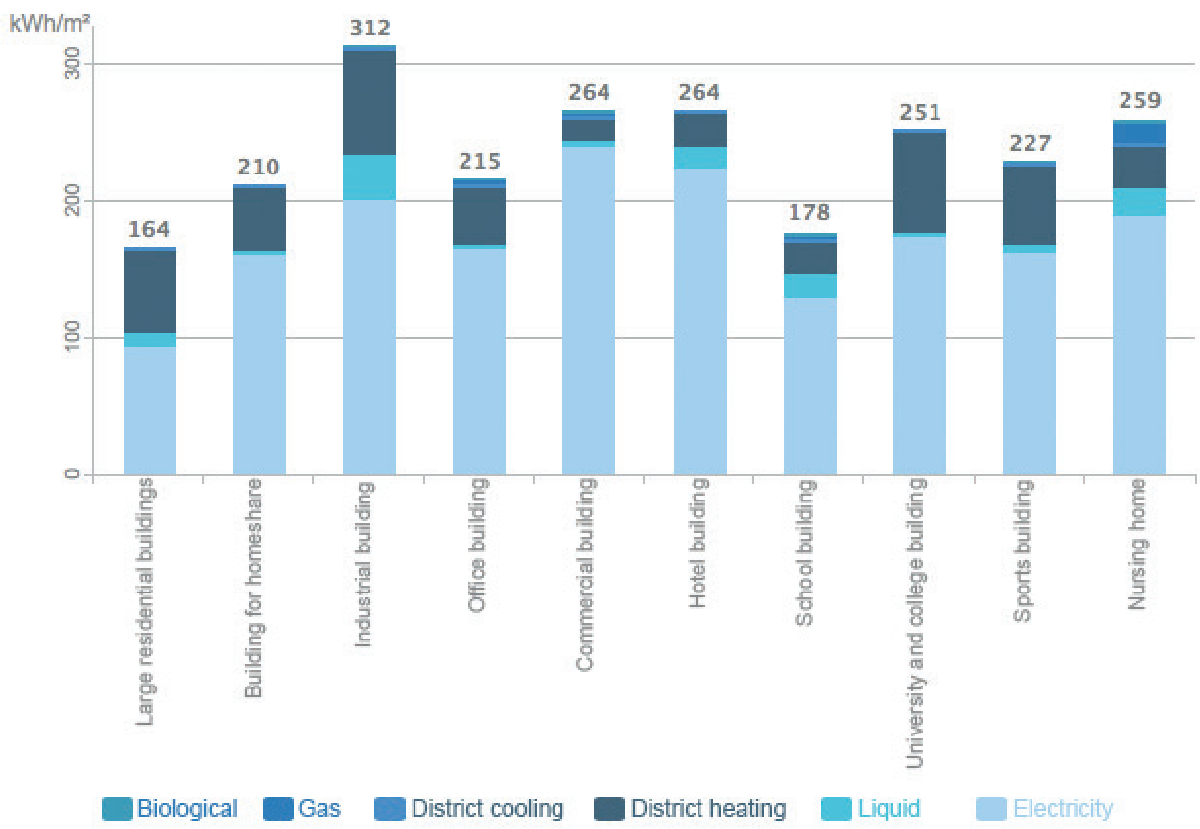

Figure 5 - Edited overview of energy use in 2011 (Enova 2014).

There are several organizations who focus on energy efficiency in buildings. One of these organizations are Entro, which is an advisory consulting organization with a focus mainly on energy and environment, located in Trondheim, Oslo and Stockholm (Entro 2014a). Entro has a monitoring tool (Entro Optima) which is available online for users. This monitoring tool helps to give an overview of the energy use in buildings (Entro 2014b).

Determination of total energy use and performance can be calculated according to standard NS-EN 15603:2008 (Standard Norge 2008). This standard presents a general framework for assessing the total energy use in a building, and also lays the basis for calculation of energy ratings in terms of primary energy, parameters or emissions of CO_2. There are separate standards for calculating energy use by for example heating, cooling, hot water, lighting or ventilation. These standards are used in combination to show the total energy use according to NS-EN 15603:2008 to present an overview of the total energy use in buildings (Standard Norge 2008). Measurement and verification of energy use may also be done according to NS 3031:2007 (Dokka & Grini 2013).

2.4.1 Measurement with technology and systems

Measurement of energy use requires an installed building management system (BMS) or separate sub-monitoring devices for energy (Dokka & Grini 2013). A BMS is a system for the management, regulation and supervision of the technical installations in the building (NVE 2013). For non-domestic buildings, it is desirable that the installed measurement structure reflects the layout that exists in NS 3031:2007 (Dokka & Grini 2013). Figure 6 below shows an edited recommended measurement structure for non-domestic buildings.

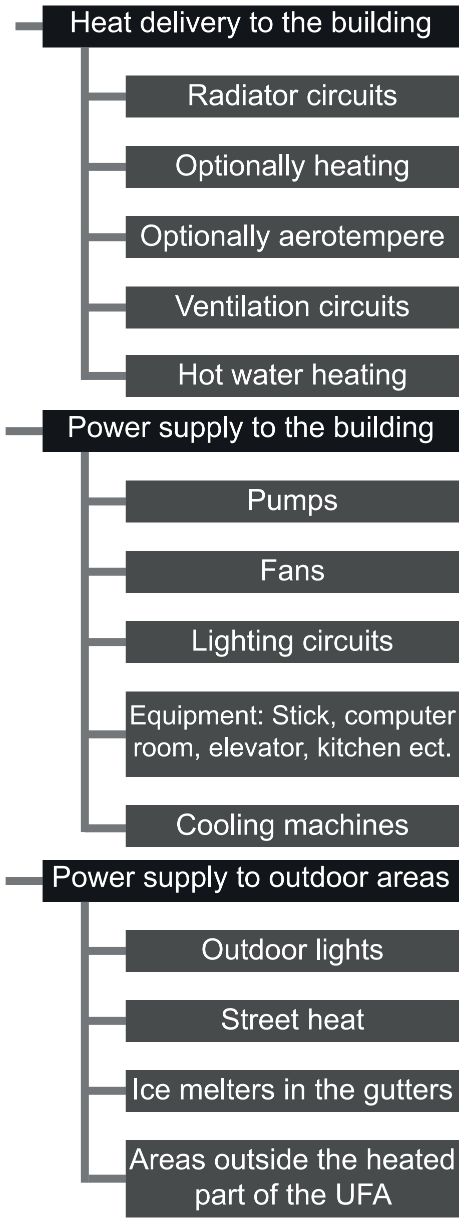

Figure 6 - Edited overview of recommended measurement structure for non-domestic buildings (Dokka & Grini 2013, p. 45).

In figure 6, the main monitors has a dark grey background, while the sub-monitoring devices have a medium grey background. Monitoring devices that can not communicated data is considered to be outdated. According to measurement of energy use, it is important with monitoring devices which can communicate data to the data acquisition systems (Dokka & Grini 2013). Energy monitoring is an important tool related to energy efficiency (Enova 2004). Energy monitoring can be described as "[...] a systematic and periodic control of the energy access and energy use, where energy use is compared with the outdoor temperature, assessed against produced commodity" (our translation) (Enova 2004, p. 4). This shall be compared against parameters influencing energy use (Enova 2004). A energy monitoring system (EMS) is a tool to get a overview of energy, water and waste data (NVE 2013). EMS is an important activity and system to reduce energy use and help to keep control of the energy data in buildings (Enova 2004).

Measurement of electrical energy consists of implementing measuring instruments (monitoring devices) in the circuit between the consumption place and the supply place. There are several types of monitors and energy meters to measure electric energy, and it is becoming more and more common with main monitoring devices with automatic meter reading and a two-way communication with the grid owner (Dokka et al. 2011).

Measurement of thermal energy consists of inserting measuring instruments to measure water volume and temperature differences in the water circuits. Energy meters for thermal energy can be installed on different levels, from the main monitors for hydronic energy, circuit meters on the pipe circuits and meters on radiators. It varies between manual and automatic meter reading (Dokka et al. 2011).

Measurement of efficiency degree of heat recovery, specific fan effect and air flow are very important parameters for a building's energy use, especially for non-domestic buildings. Air quantities and effect usage of ventilation fans must be recorded to measure the specific fan effect. This describes the effect factors of the air distribution system (Dokka et al. 2011).

Expected energy use can be calculated or be based on measured values of specific energy use. Expected energy use for a non-domestic building built according to technical building regulations can be calculated in regard to NS 3031:2007. Measured energy data are usually collected from energy monitoring systems. The measured energy data provide a good indication of what the specific buildings actually uses of energy - the actual energy use. Measured energy data may be used to indicate expected energy use. Expected energy use is also based on assumptions and experiences in regard to different factors involving the building (NVE 2013).

2.4.2 Impact factors on energy use

Energy use in non-domestic buildings will be affected by a number of factors and choices made throughout the life of the building. Factors and choices from the planning, design, construction, takeover, operation, maintenance and use of the building will impact the buildings energy use and efficiency. The choices are influenced by government requirements, building technical capabilities, as well as the owner and users desires, priorities and requirements (NVE 2013).

It is the building owner who make the crucial choices about the location, structure, specifivations, solutions and construction process. The government set the requirements and the available technology for installations, components and systems affect the choices. All these factors will lay the basis of the building, which will impact the energy use later on, when the building is taken over and the operation and use phase start (NVE 2013).

The energy use will be further affected by whether both the building and the technical installations and systems are constructed and carried out as planned and that they work optimally and as intended, together. The technical installations and systems need to be tested, adjusted and set correctly to work optimally (NVE 2013).

Good facilities management can improve indoor air quality and temperature control, while not wasting energy unnecessarily (NVE 2013). Facilities management is a central factor in regard to energy performance and use. Facilities managers has the responsibility to manage, operate and maintain the building. If facilities management activities are carried out in an optimal way, it may result in a more energy efficient building (Menezes et al. 2011).

Users affect energy use in non-domestic buildings by their requirements for indoor air quality and temperature and their behavor towards the choices of equipment, devices and active choices like to turn off equipment, devices or lighting when it not needed (NVE 2013). Users and their behavior is therefore a central factor in regard to energy use and efficiency. While users of non-domestic buildings not always have direct control over a buildings indoor climate, they influence the energy efficiency through their behavior and requirements (NVE 2013, Menezes et al. 2011).

The direct impact factors for existing non-domestic buildings are technical installations and systems, operation and management systems, equipment, devises and the outdoor tempereature. Techincal installations and systems include heating systems, cooling systems, ventilation systems, fans, pumps, and lighting (NVE 2013). The operation of the technical installations and systems is a big impact factor for the energy use and energy efficiency in a non-domestic building. The reason for this is more complex technical installations and systems that need to be operated, which gives room for error and un-optimal operation of buildings. While there are technical building regulations that state requirements for the technical equipment to be installled, there is no requirements for how the buildings should be operated optimally. A lack of focus on monitoring energy use will not lead to an optimal operation of the technical installations and system, which will reduce the building energy efficiency through higher energy use (NVE 2013).

Energy management and leadership to make sure there is a close and focused monitoring of energy use and optimal operation is imporant and will depend on expertise and a feeling of ownership. Important impact factors for energy use in regard to operation may be; leadership, expertise, experience and motivation, focus on building technical solutions and interaction, inspection, troubleshooting and maintenance of technical installations and systems during operation, and last but not least, to utilize the managing capabilities of the technical installations. A EMS and a BMS with installed energy monitoring devices makes it easier to visualize energy use to get the right basis and focus on energy management (NVE 2013).

Elevators use a lot of energy, but is often required from a universal building perspective. Equipment such as computers and printers has become more energy efficient, but there are more equipment and devices now than before (NVE 2013).

Energy costs in Norway has increased since 2000 - both for electricity and oil. Electricity was at ~ 0,33 NOK/kWh and oil was at ~ 690 NOK/barrel in 2012, compared to ~ 0,14 NOK/kWh for electricity and ~ 260 NOK/barrel for oil in 2000. This is figures based on the service industry. Energy prices are one factor that affects energy behavior. This is because low energy prices often leads to a lower focus on measures to reduce energy use, since we can use more energy for a lower cost. With this in mind, it is very possible that higher energy prices have partly led to a greater focus on energy use and energy efficiency in non-domestic buildings (NVE 2013). Electricity is the most used energy commodity. About 80 percent of energy use in residental and non-domestic building are covered by electricity and can be explained by that most devices are electric. In non-domestic buildings, electricity is used for technical installations, systems, lighting and equipment etc. Electricity for heating of buildings varies with the outdoor temperature, but new technologies such as air to air heat pumps has reduced the growth in annual energy use (NVE 2014).

The outdoor temperature is an imporant factor for energy use, since heating of buildings use a lot of energy. Heating varies with the outdoor temperature and the energy use of buildings will vary depending on warm and cold years. To make the energy figures comparable and to get a more accurate picture of energy use over different years, the energy use are normalized by a temperature correction. Temperature correction is an important method to display the energy use correctly for different years (NVE 2014). To calculate the temperature corrected energy use - the following formula may be used;

“Energy use$_{tc}$ = Energy use$_{m}$ * [(Proportion$_{td}$ * (DDF$_{ny}$/DDF$_{my}$)) + Proportion$_{ti}$]” (our translation and changes) (NVE 2014, p. 44).

The following explanations help to understand the formula;

“Energy use$_{tc}$ = temperature corrected energy use
Energy use$_{m}$ = measured energy use that year

Proportion$_{td}$ = proportion of temperature dependent energy use
Proportion$_{ti}$ = proportion of temperature independent energy use
DDF$_{ny}$ = number of degree day figures in a normal year
DDF$_{my}$ = number of degree day figures that year" (our translation and changes) (NVE 2014, p. 44).

A degree day figure (DDF) is a measure of how cold it has been and how much energy that is used on heating (NVE 2014).

Changes in temperature is described as the most significant factor for the development of energy use (Døhl, Ø. 1999). Average annual temperature has increased by about one degree celsius since the reference period of 1961-1990 to 2011. Increased temperature will not necessarily result in a lower energy use for non-domestic buildings. There might be less energy needed for heating, but at the same time more energy is needed for cooling (NVE 2013). For Trøndelag, the area in Norway where Trondheim is loacted, the average annual temperature is somewhere between one and six degree celsius based on the reference period of 1961-1990 (Meteorologisk institutt 2014a).

In figure 7 below shown an overview of temperature deviations from normal per year for Trøndelag.

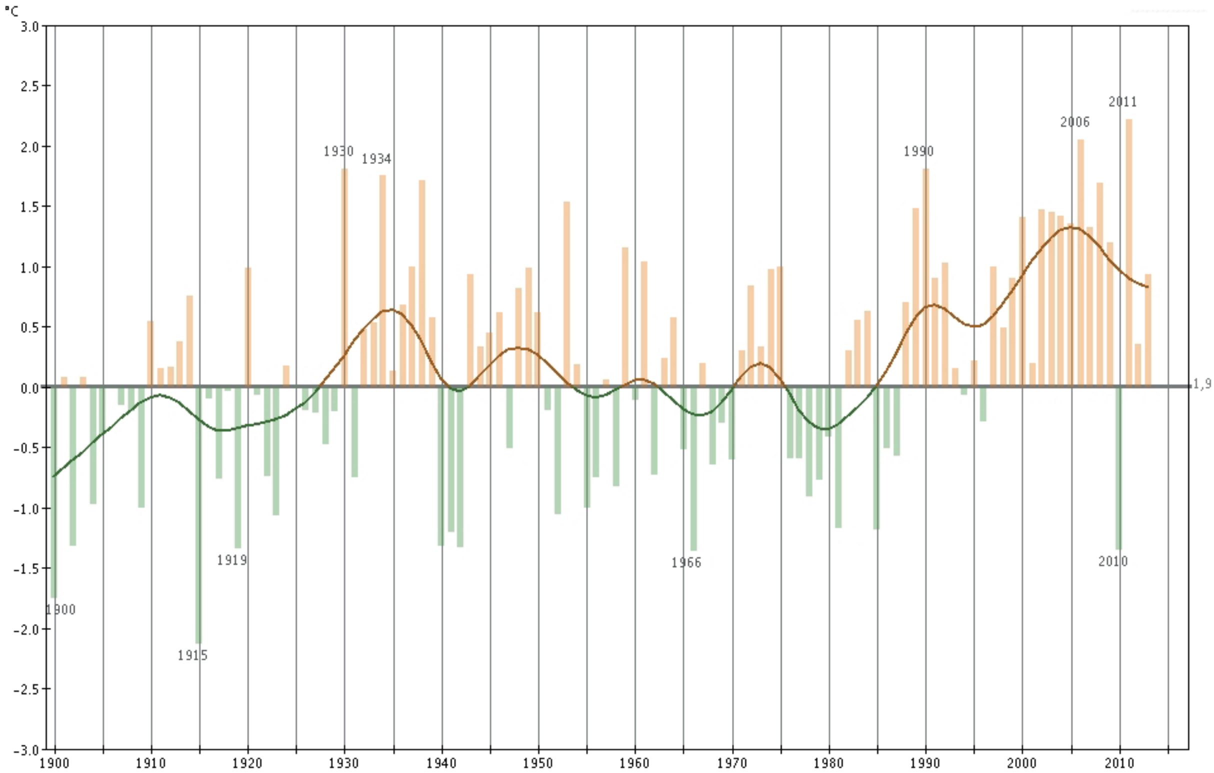

Figure 7 - Overview of temperature deviations from average annual temperature per year for Trøndelag (Meteorologisk institutt 2014b).

The main temperature development trend for Trøndelag the last 100 years is that it has gotten increasingly hotter. The temperature in the periode of 1900 until approximately 1985 was close to the average annual temperature. From 1985 towards 2007 it has gotten warmer than normal (Meteorologisk institutt 2014b).

The growth in population in Norway is also a driver for higher overall energy use, while passive houses and low energy buildings have helped to reduce the growth in energy use (NVE 2014). Population growth is an important long term factor if you look at the energy use in the whole of Norway, but it might also be an imporant factor in the future of non-domestic buildings, because more population will result in larger non-domestic building area as a result of a greater demand for employment (NVE 2014). An other important factor is economic growth. Economic growth can be connected to the energy use in non-domestic buildings because a better economy often result in a higher demand for services and goods, which again result in a greater production and use of different building types (NVE 2014). Although population and economic growth are important in a long term perspective, these are macro-economic issues which we will not have a focus on in this master's thesis.

2.5 Management towards best practice

2.5.1 Facilities Management

Management of facilities is called facilities management in british, facility management in american english and is often shortened to FM (Mørk, Bjørberg, Sæbøe & Weisæth 2008). Facilities management is a field that is relatively new in Norway and is constantly evolving (Sæbøe & Blakstad 2009). After NS 3454, facilities management includes all activities within the concepts of management, operation, maintenance, development, service and potential in real estate (shorted to FDVUSP in norwegian) (Mørk et al. 2008). When we in this master's thesis write management, we refer to facilities management as a whole.

40 years ago there was little talk of facilities management as a separate expression and discipline. Buildings were taken care of by maintenance, cleaning and operation, but any more and a common expression was not determined. Over the years, facilities management has been recognized as a expression, discipline and service sector, and have gained their own standards, codes and vocabulary (Atkin & Brooks 2009).

For facilities management, there is not a definition or formulation that will fit all situations. Approaches of facilities management will vary from organization to organization, although they operate in the same business sector. Facilities management can partly be described as activities to create an environment that supports the implementation of an organization's primary activity (Atkin & Brooks 2009). One definition is: ”An integrated approach to maintaining, improving and adapting the buildings of an organisation in order to create an environment that strongly supports the primary objectives of that organisation" (Barrett & Baldry 2003, p. xi). This definition focuses on the physical infrastructure, instead of support services (Barrett & Baldry 2003). Barrett & Baldry (2003) emphasizes that the other aspects must not be excluded. Another definition is: "[...] a profession that encompasses multiple disciplines to ensure functionality of the built environment by integrating people, place, process and technology" (Atkin & Brooks 2009, p. 4). This definition was written by The International Facility Management Association and illustrates that facilities management is larger and depends on several factors besides the physical infrastructure for viral success (Atkin & Brooks 2009).

CEN (Comité Européen de Normalisation) agreed in 2006 on an official european definition (Sæbøe & Blakstad 2009). The definition of facilities management is presented in the standard NS-EN 15221-1 and reads as follows: "Integration of processes within an organisation to maintain and develop the agreed services which support and improve the effectiveness of its primary activities" (Standard Norge 2007a, p. 5).

We will relate to this definition and standard NS-EN 15221-1 in this master's thesis. In NS-EN 15221-1, a model that shows the various processes and parties in facilities management is presented. This model is shown in figure 8 below.

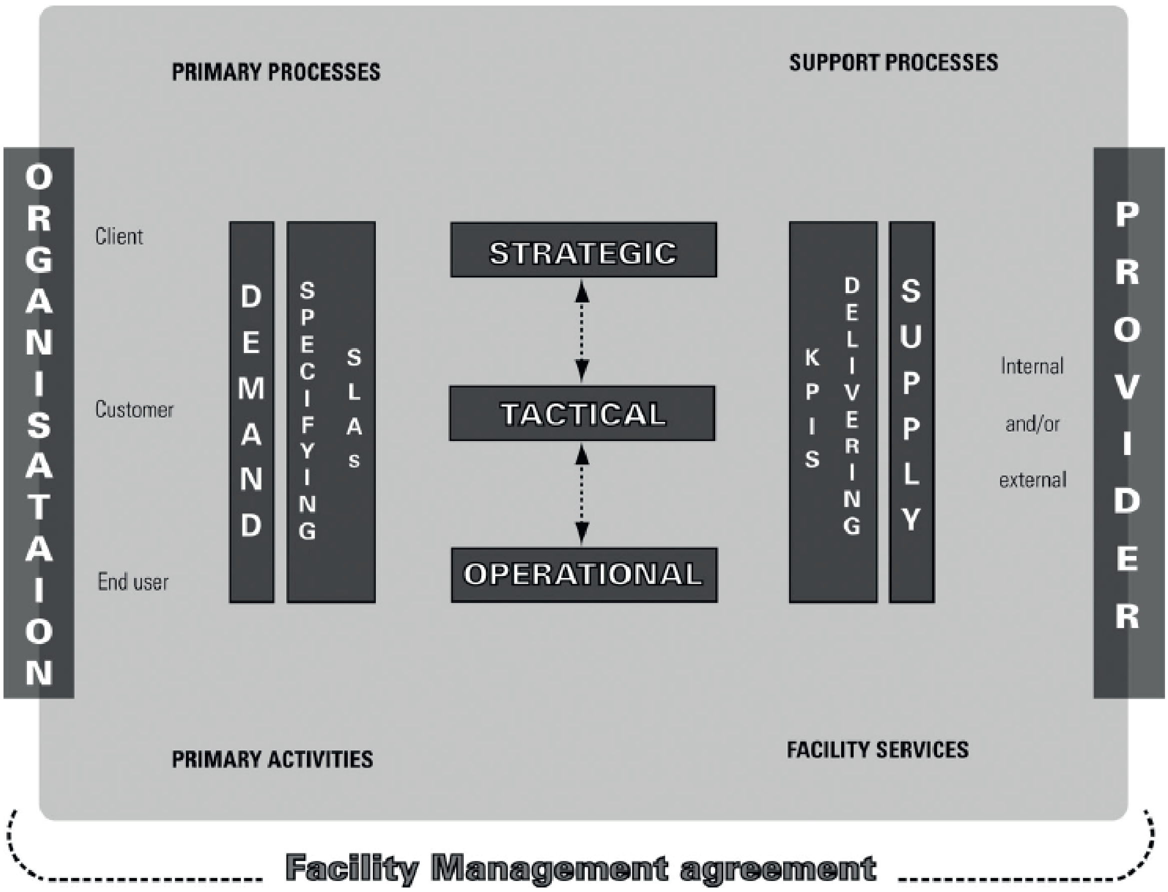

Figure 8 - Model of facilities management processes (Standard Norge 2007a, p. 8).

This model tries to give an overview of how various processes in facilities management works in collaboration between the organization (client, customer, end user) with demand and supply (internal/external) with deliveries - over three different levels (strategic, tactical and operational). An organization's primary activity is its core business. Needs are defined in a service level agreement (SLA) and the delivery of facility services is measured through defined key performance indicators (KPI) (Sæbøe & Blakstad 2009). A service level agreement (SLA) is a contract between client and provider of facility services. A service level agreement clarifies the terms, performance and measurement for the delivery of facility services (Standard Norge 2007a).

Key performance indicators (KPI) is a main indicator of performance of the delivery of facility services. The KPI can be used in conjunction with the monitoring and measurement and in regard to SLA to identify best practice (Standard Norge 2007a).

The standard NS 15221-1 has split the responsibilities, scope and structure related to facilities management into two categories; space and infrastructure and people and organization. Services in regard to space and infrastructure relate to accommodation, workplace, technical infrastructure and cleaning among other related services. Services in regard to people and organization relate to healt, safety and security, hospitality, information and communication technologies and logistics among other related services (Standard Norge 2007a). The facilities managers act as a link between the sides of demand and supply, where they are responsible for the integration of processes within an organization, on a strategic, tactical an operational level (Standard Norge 2007a, Junghans 2012).

Facilities management has, as written, evolved over time and is still evolving today. Now there is a greater understanding and acceptance for the management, operation and development of the buildings as an integrated process to support the organization's primary activity - that is, the core business. Facilities management terms includes different roles and it is common to distinguish between user, manager and owner (Sæbøe og Blakstad 2009).

2.5.2 Organization

Barrett & Baldry (2003) writes that various management departments differ from each other. This is mainly because they have evolved based on the needs of the organization they are associated with, but can be structured after five models (Barrett & Baldry 2003). In the first model, called an office manager model, facilities management is generally not a separate function, but the responsibilities and duties is given to a single person - for example; an office manager. The reason for this may be that the organization only operates from a small building which eliminates the need for a large management department , or that the organization is renting the building and therefore do not allocate staff to facilities management, but rather choose to give this responsibility to consultants as needed (Barrett & Baldry 2003).

The second model, called a single site model and applies to organizations that are located in one building and is large enough to have its own management department. The organization tends to own the building and will therefore often spend more time and money on administration than the organizations who rent buildings. The choice often point towards creating a management department that takes care of facilities mangement through a combination of internal and contracted services (Barrett & Baldry 2003).

The thirt model, called a localised site model, mainly apply for organizations that have buildings in multiple locations within a larger area - such as a city, but may also apply across the country. It is common to have a headquarter (which takes decisions on a strategic level) and a degree of decentralization. The greater the degree of decentralization, the greater the likelihood of external contractors (Barrett & Baldry 2003).

The fourth model, called a multiple sites model, apply to large organizations that operate across geaographical areas, but still operates on a national level. In this model, organizations have headquarters where the management departments mainly draws strategy and policy (on a strategic and tactical level) which is further transferred to smaller headquarters and branches (Barrett & Baldry 2003).

The fifth and final model, called an international model, apply for large international organizations who operate across national borders. Management departments is located in the headquarter and also here make decisions and draws strategies and policies. The regional and national offices will mainly be controlled by them selves and follows the specific strategy and policy drawn at the headquarter. The regional and national offices will be responsible for operational activities (Barrett & Baldry 2003).

2.5.3 Benchmarking

Facilities management has over time become a co-ordinating management function that focuses on the boundary between physical conditions and people. Buildings play a major role in maintaining and strengthening the core business of an organization. To understand the building's role, it is important to assess the building performance as a result of facilities management (Douglas 1996).

Figure 9 on the next page show facilities management and building performance are linked. Building diagnostic is the intersecting area in the figure. According to Douglas, building diagnostic is a "[...] systematic study and evaluation of building performance" (1996, p. 27). Measurability is important and crucial for understanding how things are related. Benchmarking is therefore central to facilities management (Douglas 1996).

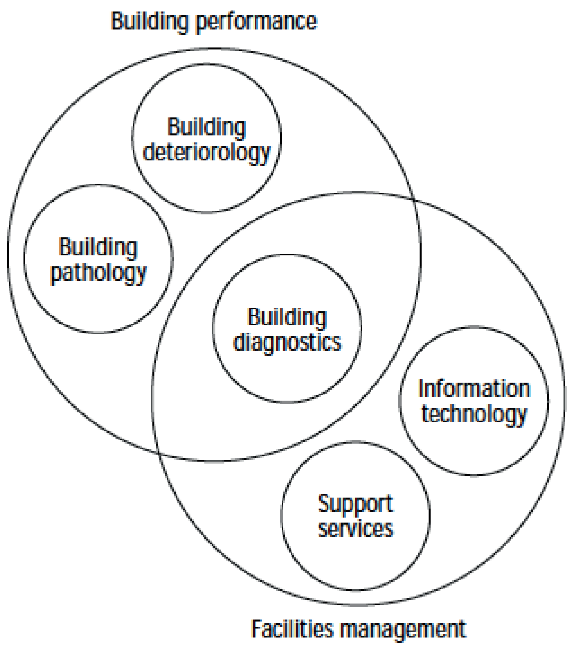

Figure 9 - Intersection between facilities management and building performance (Douglas 1996, p. 27).

According to the norwegian standard NS-EN 15221, benchmarking is defined as a "process of measuring performance (including price) of facility services and comparing the results internally and/or externally" (Standadard Norge 2007a, p. 5). Another definiton of benchmarking is "the continuous process of measuring products, services and practices against the thoughest competitors or those companies that are recognized as a leader in the industry" (our translation) (Sæbøe & Blakstad 2009, p. 30). Benchmarking of energy efficiency can be used to monitor changes in the energy efficiency of buildings (Chung, Hui & Lam 2006). This is where best practice comes in. Benchmarking is mostly interpreted as an economy bounded tool used to compare actual costs with the costs associated with best practice (Douglas 1996). Benchmarking of building performance can be divided into two primary categories: cost centered and non-cost centered. The first is of quantitative nature (such as heating costs in kWh/m^2 per year), while the second is of a qualitative nature (such as evalution of quality or efficiency) (Douglas 1996). An important part of benchmarking is to analyze the results with the aim of investigating the background of gap between measurements and benchmarks. An analysis of the gap is the basis for assessment and improvement. The analysis can contribute to the proposed plans for improvement. After improvements have been made, new measurements should be made to identify improvement (Kincaid 1994).

A benchmarking process may consist of five phases. The first consists of planning what is to be benchmarked. The second phase is a search process to find a good partner to benchmark against. The third phase is to observe and analyze the partner. The fourth phase is to find and analyze the causes of the gap between you. The fifth and final phase is to customize improvement measures and then implement these (Mørk et al. 2008).

2.5.4 Energy efficiency

Politicians have directed their attention towards energy efficiency. This is mainly due to concerns about global climate change linked to carbon dioxide emissions (Jaffe, Newell & Stavins 2004). There is also attention on energy efficiency since building account for around 30 to 40 percent of a nation's energy use, and because wasted energy is within the similar amounts, which ultimately indicate that there is a great potential in energy that could be saved - leading to a focus on more energy efficient buildings (Atkin & Brooks 2009). Energy efficiency can be described as follows: ”[...] energy efficiency refers to using less energy to produce the same amount of services or useful output [...]” (Chung et al. 2006, s. 2). Energy efficiency has been recognised and practiced for some time, but it is only in recent years that buildings are look at with a whole-life or life-cycle perspective. Buildings have adapted, but mostly in regard to stringent legislations and regulations (Atkin & Brooks 2009).

Buildings are getting more complex and require a management and operation to respond to rapidly changing demands and conditions. Control over installations such as heating, cooling, ventilation, lighting, power, security and fire systems among others is vital for the building to perform optimally, meet user comfort demand and for energy not to be wasted. To manage this there must be viable information on the conditions both inside and outside of the building. This information is mostly dependent on monitoring, sensing and control, which must be supported by technology to be managed. Accurate information are necessary to make important decisions so that services can be controlled and performance regulated, impacting the building. Building automation systems and intelligent buildings (or smart buildings) are important terms in this regard (Atkin & Brooks 2009).

Automation of buildings ”[...] implies a computerised system that oversees and controls building operations, energy and safety management” (Atkin & Brooks 2009, p. 147). Developing one system to manage all functions and services on the other hand is both costly and difficult, but a system interface with access and control over heat, cooling, ventilatin, lighting power, fire and secury among others is likely and depend on fast communication. A typical automated system will maintain the indoor climate, manage energy measures and monitor system behavior and equipment (Atkin & Brooks 2009).

Intelligent or smart buildings ”[...] use technology to improve the internal environment and support functions for users” (Atkin & Brooks 2009, p. 148). An intelligent building is designed to control the building internally and externally through technology and communication solutions based on zone control, monitoring and sensing. Technology could optimally monitor and sense light, humidity, temperature and users among other factors and send the information to a system that would regulate energy use in different rooms and zones in a building - optimizing the energy delivery and use (Atkin & Brooks 2009).

Although technology may be a step in the right direction, complex and technology dependent buildings raise concerns since responsiveness to change is an important and fundamental requirement for intelligent buildings (Atkin & Brooks 2009). Atkin & Brooks (2009) argue that no buildings will support a organization if change is not possible. While anticipating change is possible, predicting the future is not. Therefore, accommodating the future, is an important aspect of intelligent buildings and their design. Most buildings are based on a fixed design and purpose, making adaption difficult. An intelligent building will rely on the possibility to develop and adapt (Atkin & Brooks 2009).

There should be an overall goal that buildings last as long as possible and function optimally to support the core business of the organization using the building. It is essential that buildings can change over time to fit the changing and varying demands of the organization. Buildings that can not satisfy the need of the organization that occupy it, may become ineffective - or rather - expired. A buildings abilities to function, change and adapt may be called adaptability and functionality (Bjørberg, Larsen & Øiseth 2007). A buildings adaptability may be represented through the terms of flexibility (the freedom change within the same function - to reorganize UFA without changing carrying system and cores), generality (flexibility, and freedom to change function) and elasticity (the option to extend or reduce area within a given geometry). The need for adaptable buildings will vary in regard to the intended purpose of the building - making the degree of adaptability determined and based on the core business. This will also mean that a building may have low adaptability and still function optimally for its purposes (Bjørberg et al. 2007). Through an assessment of important factors for different building types, buildings may be rated according to the degree of adaptability they should have. It is also important to have in mind that buildings of different age are built in different ways (Bjørberg et al. 2007).

Junghans (2012) states that energy efficiency in non-domestic buildings is more than a technological challenge, indicating that energy efficiency is directly related to management, operation and use. For existing buildings, improved energy efficiency mainly focuses on three areas; organizational measures, technical measures and architectural measures. The organizational measures is related to improving the use and operation of buildings. That is, the user behavior and intensity of use, aswell as measures to control facility management services in the building. The technical measures consists of a modernization of technical systems. Architecural measures can be modernized building construction. Both engineers and architects are involved and responsible for activities to improve the energy efficiency in buildings (Junghans 2012). Junghans (2012) argues that the organizational measures are left out since this is not the main focus for engineers and architects. There has also been performed less research in regard to management, operation and use of buildings (Junghans 2012).

There are different methods, theories and approaches available to improve energy efficiency. One approach is to start a preliminary project to assess and produce a realistic overview of an organizations potential for reduced energy use, energy costs and environmental costs. Based on the preliminary project, a main project may be introduced. This main project may be called a energy program - and is long-term commitment to improve the overall energy management, where all imporant energy matters are included. This result in a energy program including important aspects like building and technical aspects, organizational aspects, operational aspects, information and funding. A energy program may take several years and include a long-term and comprehensive change process with a stronger energy management through better practices in energy-realated operation and adequate energy awareness among users (Entro 2014c). Entro (2014c) states that energy programs may achieve a reduction in energy use of 25 percent.

Energy management is an other (or a further) approach to take on towards a more energy efficient building. Energy management may be established through an international standard called NS-EN ISO 50001. Working towards improved energy efficiency is often a task that intervenes in different levels of an organization, and thus may be established through leadership, which should have the best overview of the organization. When energy management is being implemented as a part of an organizations management structure, where energy is a factor which is reported and followed up on with the same importance as other aspects, it should be possible to identify and manage opportunities that may contribute to reduced energy use and costs. Energy management is similar to other management processes where you plan, carry out, control and monitor. Often it is only necessary to implement and establish a focus on energy in the management structure and agenda on the same line with HR, HSE and finance among other management topics (Enova 2012b).

The main task in a simplified energy management system is to set goals, organize efforts, assessment of energy use, prepare and set up an action plan, monitoring of energy use and key figures, evaluate efforts and other simple procedures. Through these tasks a process is established to work systematically on energy use where the management is involved and where the objectives and plans are seen throughout the organization (Enova 2012b). When the developments in energy use is monitored and followed up on, it is possible to find out how it can be used more efficiently. A continuous monitoring of energy use is important in order to identify improper operations, errors in technical installations, less appropriate habits an other impact factors. When the efforts, work and results are assessed and evaluated, it is easier to look forward to further efforts and give the management a basis for new initiatives and objectives (Enova 2012b).

Managers need to have a focus on energy use to make any significant changes. With good support from managers and motivated and skilled operators, it is estimated that energy use can be reduced with around 20 percent. The realization of this potential is related to increased focus on energy use, monitoring of the operating personnel and monitoring of time management. In addition, it is essential that attention is so sufficient that errors can be detected and corrected fast since errors is an explainations for high energy use (NVE 2013). Thema Consulting Group (2012) has conducted a study indicating that optimal operation of buildings is an important factor to reduce energy use in existing office buildings and to meet energy requirements. Junghans (2012) indicate the same, and specify that close knowledge to different aspects of the building, such as different condictions, possibilities and challenges, form the basis for best practice in regard to continuous improvements of existing buildings - and that it is different types and roles of operatiors who have this knowledge. Operatiors may be described as a ”super-user” (Junghans 2012, p. 6). The difference between a user and a super-user is that a user of a non-domestic building do not see the energy use - it is invisible to them - while for an operator (super-user), energy use is visible as they see both the users and the technology aspects related to energy use and efficiency (Junghans 2012). Junghans (2012) anticipate that operators are obvious candidates to improve the day-to-day energy use, and thus the energy efficiency, by being a lead user, making energy use visible for the users and act as a link to identify and support improvements. Bye (2008) also desribe the operators as users of the building, but a different users that the regular users - also called end-users. The operators’ usage of the building is about making the technological solutions work in the best possible way. What that can be defined as the best way is debatable, and may be affected by users and their needs, energy efficiency, economy and regulations (Bye 2008). To optimize the operation, a operator may take on a dual role between the operation and usage - working towards a more energy efficient behavior in the users and also making sure the building is operated optimally based on the mediator role and the input and output that may consist of (Bye 2008).

Costs associated with investment in construction, rebuilding, demolition, annual management, operation and maintenance of buildings are high. In this context it is important that resources associated to these costs is kept as low as possible and viewed in a holistic perspective of the building’s life while the desired quality is maintained. A method to accomplish this is to focus on the building’s life cycle costs (Bjørberg et al. 2007). Life cycle costs is the sum of capital costs, costs of management, operation, maintenace and development in the use and operating time of the building, and also residual cost of disposal. The interest and focus on life cycle costs are increasing, and many see the benefits and importance of considering the investment costs associated with the subsequent costs of using the building (costs incurring both periodically and annual to maintain a functional and technical standard) (Bjørberg et al. 2007). Life cycle costs may be interpreted as a key to achieving better value of the invested assets. To use the life cycle cost method and analyze it is possible to assess the impact of possible alternatives, thus allowing to evalute towards the solution which is most cost effective and reducing the risk of failure and loss of functionality in the building (Bjørberg et al. 2007).

It is imporant to see a problem from different angles when you use an analysis of life cycle costs (LCC). This is so that you can come up with different solutions. The decision process can be divided into four phases; task description, choice of options, analysis of options and discussion towards a decision. It is important to reflect upon the task, how large the task is, desired achievement or result, need of assistance, need to establish a long-term comprehensive plan and budget estimates. Assistance from advisors may help find and estimate additional information on materials, time frame and other important factors such as life times, guarantees, maintenance and operation data (Bjørberg et al. 2007).

For energy, cost depend on on these factors; location, temperature, building shape and size, scale of technical installations, facade design, windows, insulation, lighting, ventilation system, heating system, heating and energy sources, cooling systems, water and wastewater, elevators and use intensity. Zoning and operating procedures with control and regulation make major impact on energy use in terms of human influence in regard to how much areas are in use (Bjørberg et al. 2007). Requirements from users and owners may also have a major impact on costs. An assessment of the extent related to internal personel versus outsourced services will also affect the costs. An additional factor may be the use of rent principles such as internal rent. This can provide a better overview and clarification regarding roles, user impact, space efficiency and better visibility of costs (Bjørberg et al. 2007).

2.5.5 Barriers against energy efficiency

A possible potential for existing buildings may be to achieve the requirements in TEK 10 and/or energy label C. For existing buildings, this will require good planning and coordination to implement, while regulatory requirements are maintained (Enova 2012a). It may be easier to facilitate energy efficient solutions and measures for new buildings, than to improve existing buildings because of different factors like construction, building body, room and zone partitions and so on. Maintenance and rehabilitation of existing buildings will often lead to a period of time where operation and use of the building will be different, which may prevent a focus on energy efficient solutions through an holistic approach (Enova 2012a).

Even though there are several approaches towards improved energy efficiency - there is also something called barriers against energy efficiency measures. Different studies indicate different indications of these barriers, such as; lack of availability of knowledge and expertise, legislation, organization, public support and lack of funding (Enova 2012a). Enova (2012a) reports, based on a study conducted by Multiconsult and Analyse & Strategi, that there are different types of barriers; practical barriers, technical barriers, economic barriers, attitude barriers and knowledge barriers. Some barriers may be placed within more than one category (Enova 2012a).

For existing buildings, barriers against energy efficiency measures, that are categorized as a practical barriers may be:

- Governments regulatory requirements is not consistent, and there is rather a conflict of interest between different government agencies. Yes, the government wants energy efficiency, but regulatory requirements to indoor air quality result in measures being undertaken (Enova 2012a).

- The relationship between the tenant and the owner of a building, the responsibilities and the allocation of costs between them. The problem is that the building owner is the one to invest in the measures, while the tenant is the one to gain through reduced energy costs (Enova 2012a).

- There is too many who have an opinion and that must be affected to work with energy efficiency measures. This is also a barrier for the operation of building (Enova 2012a).

- Energy efficiency is not rooted in the management, thus making it hard to prioritize energy efficiency measures. The operating personnel have many different tasks to be performed, and there is often too little time, risking that energy efficient measures are being abandoned (Enova 2012a).

- Energy suppliers are a hindrance because they monopolize, especially in relation to district heating (Enova 2012a).

For existing buildings, barriers against energy efficiency measures, that are categorized as a technical barriers may be:

- Lack of knowledge about technical solutions and development. This is especially a challenge in relation to the operating personnel, if they do not know about new solutions. This may also be the result of a focus towards the investment phase, rather than the operational phase. An important aspect is that an investment may not be linked to the operational phase where the investment might be earned back over time. A lack of this aspect will result in a vision that does not look positively on the profitability of the investment in the first place (Enova 2012a).

- Age of the building since it is more challenging to implement measures on a existing building that are designed so that it is hard to install modern technology and systems which could help to reduce energy use (Enova 2012a).

For existing buildings, barriers against energy efficiency measures, that are categorized as a economical barriers may be:

- Lack of profitability in relation to the measures and challenges to raise funds for energy efficiency measures. Low energy prices push down the profitability, while there are high prices for labor (Enova 2012a).

- Different interests during a buildings life cycle indicating, for example, that tenants has a low interest to pay for measures if there is little time left on the rental contract, but if there is long time left on the rental contract there are higher interest for measures since the tenant pays for the energy during the rental period (Enova 2012a).

- Energy efficiency measures are not prioritized because of the number and amount of other expenses that are seen as more imporant (Enova 2012a).

For existing buildings, barriers against energy efficiency measures, that are categorized as a attitude barriers may be:

- People are not aware of energy use, especially in Norway, because of historical energy prices and resources. Many users think that there are high energy prices in Norway, still there is no willingness by users to implement measures to improve energy efficiency (Enova 2012a).

- Negative attitudes towards measures for energy efficiency, both in users, organizations and industry. A challenge is that users are more concerned about the indoor comfort and climate instead of energy efficient buildings. It may be argued that energy efficiency in Norway is more about the environmental aspect, rather than the profitable business aspect. In other countries, energy efficiency is alot more profitable, and there is a bigger focus on cost-cutting (Enova 2012a).

- Corporate culture need to support the measures to implement them. Insufficient knowledge, lack of will and corporate culture lays a negative foundation in regard to focus on energy efficient measures (Enova 2012a).

- Entrenched attitudes in the operation industry, especially linked to new solutions (Enova 2012a).

For existing buildings, barriers against energy efficiency measures, that are categorized as a knowledge barriers may be:

- It is difficult to obtain good expertice and high qualifications (Enova 2012a).

- There is also a challenge to communicate energy efficiency measures. This may also be viewed as a lack of sales expertise, if you think about the energy efficiency measures as the product (Enova 2012a).

- Users are comfort-seeking, while not having enough knowledge about the use of the building and energy saving measures. It should be highlighted that a reduction in energy use, will not necessarily sacrifice desires for comfort and a good indoor climate (Enova 2012a).

- Lack of a long-term view, indicating that there is not enough knowledge about energy saving benefits, and how this will be provided in a long term (Enova 2012a).

- The difficulty to retain the operational personnel to follow the current requirements (Enova 2012a).

The presented barriers have different degrees of difficulty associated with breaking them down. It is often the barriers that you have control over, or may affect, which is the easiest to break down, while the barriers you have less controll over and is harder to affect and is harder to break down (Enova 2012a).

2.6 User behavior in non-domestic buildings

Management and operation of buildings has a major influence on actual energy use, at the same time, users will also affect the energy use through their daily use of non-domestic buildings (NVE 2013).

Users enter buildings, move in buildings, use buildings and leave buildings. Users may also work extra (take overtime), take vacation or get sick (Robinson 2006). Robinson (2006) describes this as stochastic processes, and underline how humans are unpredictable, making human behavior one of the most complex processes within buildings, which implicate the energy use in buildings. Users presence and interaction in buildings affect the energy use through windows, doors, lighting controls, shading devices, appliances, heating, ventilation and cooling system controls. Water is consumed and waste is produced (Robinson 2006).

While it is possible to simulate both ideal and real energy efficiency in a building based on standarized figures, indicators or measures - it is harder to fit users and their behavior into such simulations. In simulations of user behavior, human presence and interaction are often based on a perfect schedule - for example; indicating that people arrive and leave a building on concise and specific times (Robertson 2006). Robertson (2006) argues that interactions between users and the indoor environment depend on the users presence and that it is important to simulate a more stochastic perspective of user presence. Human interactions are the result of a conscious decision making process based on inputs (physical stimuli) and outputs (processing and actions). This is individual and different for each user. The decision to act can depend on many factors such as experience, response, convenience, realization and effectiveness (Robertson 2006). In regard to Aristotle (384-322 BC), every human action have atleast one or several of these causes; desire, chance, compulsion, habit, nature, reason and passion. Human behavior can be described as unexpected, irrational and inexplicable - and it may be close to impossible to predict it accuratly. With this in mind, we are left with few imperfect choices to approximate, assess and understand possible user patterns. Obervation may be a helpfull method to assess and reproduce some user patterns, since we can identify actions that are motivated by causes (Haldi 2010).

All people have different types of needs (Framnes, Pettersen & Thjømøe 2006). People act on the basis of motivation because they feel needs that they are motivated to satisfy (Nørgaard & Olsen 2009). Motivation controls our actions, and a goal is the results we want to achieve by performing an action (Schiffman & Kanuk 2007). There is no model that explains a person's energy behavior in a perfect or good way. This is not surprising since human decisions and behavior are so complex. In relation to non-domestic buildings, users will not have the same financial responsibilities related to energy as they do in their own home (Bye 2008). Studies show that better technological solutions can lead to improved energy efficiency, but this is also connected to learning processes and acceptance of the solutions. Therefore, new technology is not enough by it self to achieve improved energy efficiency and save energy in buildings (Bye 2008).

Bye (2008) writes that energy use in non-doemstic buildings is generated indirectly in relation to what happends in the building. Energy use can be thought of as an invisible tool to ensure that systems and components of the building works. Examples can be computers, ventilation, light or heating. For the users, these are important and often expected (Bye 2008). To ensure that users have it comfortable may be called ”comfort management” (our translation) (Bye 2008, p. 162). The users will have different needs or preferences for temperature. In non-domestic buildings which may have a central control of temperature this can lead to conflicts, since it is quite likely that there are users who are both satisfied and dissatisfied with the temperature (Bye 2008). Leaman, Stevenson & Bordass (2010) states that there will always be some people who are dissatisfied with the conditions in relation to a building - around 15 percent will have complaints. From a facilties management perspective, the best option is often to solve and improve the problems in regard to this spesific group (Leaman et al. 2010).

A challenge related to users and energy is that even if users want to help improve the energy efficiency, few people are aware of how they can contribute to reduce the energy use. Good measures to raise awareness can be campaigns, combined with training and real visualization of changes in the actual energy use. This might help to ensure that each user can get an impression of the energy use and their impact in the spesific building (NVE 2013). For non-domestic buildings it is especially lighting, indoor climate and equipment that could affect energy use related to users. Temperature inside the buildings can both increase and reduce the energy use considerably. In non-domestic buildings, especially in open common spaces, each user must often adapt to an average temperature. In a closed area, like an office or a meeting room there is a greater possibility of opening windows, regulate a radiator or turn off the light (NVE 2013).

To reduce users impact and influence on energy use in non-domestic buildings, automated and stand-by solutions might be good alternatives to reduce users' opportunities and possibilities to influence energy use, which might lead to more energy efficient non-domestic buildings (NVE 2013).

Technical building regulations use a daily usage time of 12 hours per day, five days a week, 52 weeks per year as estimates for calculation of operating time in office buildings. During this time, only a small proportion of the area are utilized. This is related to activites such as meetings. By reducing energy use in areas of the building that are not in use, energy use can be significantly reduced, so that energy use is optimized and not used more than is actually needed. Management of overtime and flexible usage of the building will also have a major impact on energy use, especially if users require optimal indoor climate, even though there are few people using the building (NVE 2013).

2.7 Summery of theory and literature

We will use references to specific sections in this chapter.

A standard called NS 3457-3:2013 is used to classify a building type, which is based on the building's function (2.1).

Technical building regulations have adapted and developed over the years, and there is now a higher focus on energy use and efficiency in buildings (2.2.1, 2.2.2, 2.2.3). The development is moving towards low-energy building or passive houses (2.2.4).

There are several calculation methods to calculate energy demand, use, performance and requirements, mostly based on standards (2.3.1, 2.3.2, 2.3.3). There are also used tools like SIMIEN and Excel (2.3.1).

There are several ways to measure and monitor energy use. To support this there is often installed energy monitoring devices in the buildings, which enable systems to collect the energy data (2.4, 2.4.1, 2.4.2). There are also several impact factors on energy use (2.4.3).

Facilities management include several activites such as management, operation, maintenance, development, service and potential in real estate. Therefore there are serveral processes and parties included (2.5.1), but also various organizations and structures (2.5.2). Benchmarking is an activity that is becomming more and more used in facilities management (2.5.3). There are several methods for and barriers against energy efficiency which suggest that there are potential for improvement (2.5.4, 2.5.5).

Users and their behavior is a difficult and important aspect in regard to buildings and energy use (2.6).

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Chapter 3

Research method - methods used in our master’s thesis

3.0 Research method

In this chapter we will first give a brief introduction to the term of research method. We will then write about two different research methods used to collect data or empiricism and describe the research method we have chosen to use in this master's thesis. Finally, we will discuss the quality of the master's thesis.

3.1 Introduction to research methods

A research method is a structured way to gather data about reality - also called empiricism (Jacobsen 2005). Empiricism originate from the Greek empeiria and means test or experiment. Research method may further be described as tools or teaching of the tools which is used to collect knowledge of reality. Using research methods open for a systematic thinking process where attention is sharpened and focused on what we want to figure out. The selection of research method reflects what you want to find out (Halvosen 1993), while a research design should be selected on the basis of the thesis question (Jacobsen 2005). Halvorsen emphasizes that the research method "[...] is an aid, and not a goal in itself" (our translation) (1993, p. 21).

There are many different methods that can be used to collect data about reality. A research method shall explain the steps in a study or investigation, but the research method best suited to investigate reality can be discussed (Jacobsen 2005). The choice of research method face four issues according to Jacobsen (2005).

The first issue is whether there should be an inductive or deductive data collection. The problem is about which strategy that best can grasp reality. The inductive strategy consists of going from empiricism to theory. This means that researchers seek reality with a - if possible - open mind and collect relevant data about reality. The information is further systematized and then the theory is formed on the basis of this. The deductive strategy consists of going from theory to empirical data - the opposite of inductive. In the deductive strategy, the researchers create expectations of reality from existing theory and empirical findings. The researcher takes the expectations and then goes out into reality and collects data. The data from reality are then compared with the expectations to look for deviations (Jacobsen 2005).

The second issue is about if there should be an individualistic or holistic approach. An individualistic approach presumes that it is the individual who is the most important source of data. A holistic approach is based on that it is the individual in connection and interaction with other individuals, organizations, and various contexts which give the best understanding of reality (Jacobsen 2005).

The third issue is about closeness or distance. The choice of distance is about that the researcher shall study and examine the object(s) from a distance to eliminate the researcher's influence or effect on the object or the respondent. This means that by keeping their distance from the reality that is studied, the risk of a disruption of this reality is reduced. The question is whether it is possible to decrease a research effect completely, or if it always will be a degree of research effect (Jacobsen 2005). Jacobsen (2005) writes that there always will involve some form of contact in all studies and it has been pointed out that the researcher always will affect those being researched through, for example, the choice of thesis question and the selection of respondants.

The fourth problem consists of the choice of words or numbers. This is about the choice of a qualitative and/or quantitative approach. That is if the information and data we want to collect shall consist of words (qualitative approach) or numbers (quantitative approach). It is often common to choose either a qualitative approach or a quantitaive approach - it may still be appropriate to choose a combination of the two methods for some research (Jacobsen 2005).

3.2 Research methods

3.2.1 Qualitative methods

A qualitative method or approach involves characterizing qualities or characteristics of phenomena. In qualitative methods, it is data in the form of text and words that is collected (Repstad 1993). Qualitative methods are suitable when you want to examine how people interpret and understand a given situation and allow for flexibility and openness so that there are few limits to what a respondant may say. This may contribute to a high conceptual validity. It is common to choose qualitative methods when selecting an unclear thesis question where you will delve into a small number of units and seek closeness to that or they you want to investigate. The various alternatives for data collection in the qualitative method is interviews, group interviews, observation and document examination (Jacobsen 2005).

3.2.2 Quantitative methods

Quantitative method or approach involves the collection of empirical data in form of numbers. This method should be selected when you want to examine a range of many units to generalize to several more (Jacobsen 2005). An example would be polls for the election of political parties. The quantitative method is often less demanding than the qualitative approach since it takes longer to conduct and manage, for example, interviews (words) than a questionnaire survey (numbers) (Jacobsen 2005).

3.3 Applied method

In this section we have presented the applied method that we have chosen for this master's thesis. Jacobsen (2005) writes that various types of thesis questions need different types of research design. We have, based on the task, topic, thesis question and associated research questions, mainly chosen to use a qualitative approach. We are still dependent on to obtain quantitative data on the two cases (the two buildings) from project documents, available documentation, measures performed and results in connection with the case study. These are documents that contain both text and numbers. We have chosen the individualistic approach because want to be close to the respondants through interviews as a part of the case study. This master's thesis is based on the deductive strategy since we first conduct a literature study to get an overview of the theory, which also leads to expectations, and then we conduct a case study. Jacobsen (2005) distinguishes between intensive (examine in depth) and extensive (examine in width). Beneath each of these two choices comes a choice where the intention is either to describe or explain something (Jacobsen 2005). Our thesis question is relatively unclear - it means that we have little prior knowledge about the problem we will investigate. We want to examine in depth - delve into few units - which means that the thesis question has an intensive purpose and refers to the qualitative method (Jacobsen 2005). We want an explanatory study where we explain why or how something occurred and can refer back to the thesis question and the three related research questions.

Jacobsen (2005) writes that with an explanatory study, we are looking for reasons why something happened. The thesis question, research questions and the applied research method for the study will reflect each other. Figure 10 below shows how we, on the basis of the thesis question and related research questions, have made choices towards an appropriate research design. Typically, the research design for these choices is a case study with comparison of cases (Jacobsen 2005). As it was presented in the various subtasks, we first conducted a literature study where we collected relevant theory and literature to present this in a kind of theoretical foundation for the master's thesis. We then conducted the case study of two selected cases. The cases consists of both qualitative and quantitative data, which are compared with each other and in regard to the theory and literature presented in this master's thesis. The case study will consist of a selection of two different existing non-domestic buildings that are selected based on a set of selection criteria in a systematic selection method that we have developed to find two relevant cases.

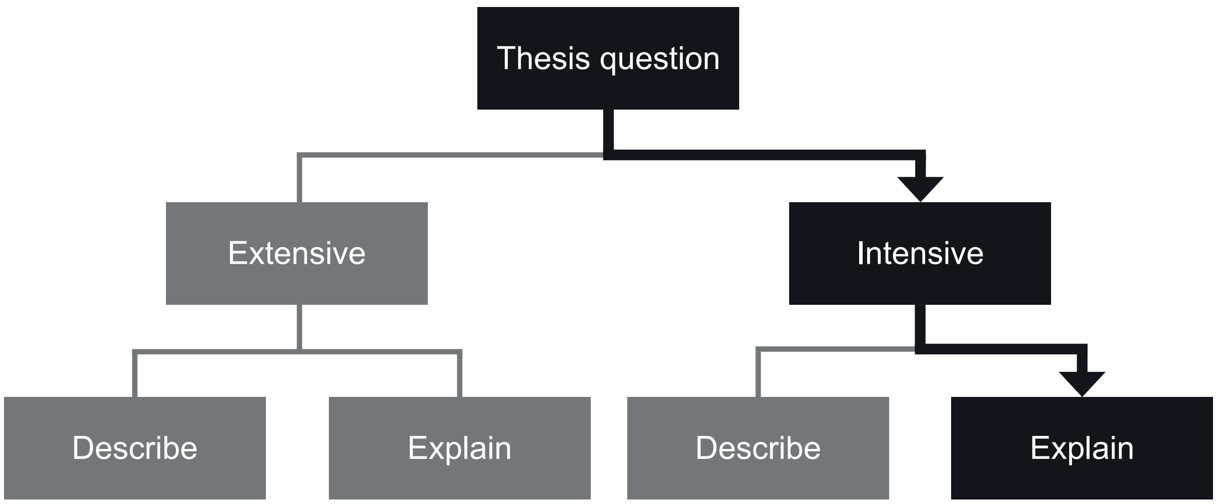

Figure 10 - Redesigned model for choice of research design (Jacobsen 2005, p. 122).

3.3.1 Literature study

We have chosen to conduct a literature study to create a theoretical foundation of theory and literature which the master's thesis shall build on. We emphasized in subtask 1 in section 1.2.2 that we should find literature that is important and relevant to different areas in relation to the master's thesis. In conjunction with the literature study, we think it is important to identify what has been written on the areas that we will be studying.

In a literature study, we see it as important to set up a systematic plan to make sure you have an overview of the literature you find while ensuring that the literature has a certain quality and relevance for the master's thesis. To achieve this, the choice of keywords, search engienes, databases, and an evaluation of citations, authors, journals and books important. The evaluation should aim to ensure that the literature has good relevance to the topic and thesis question in the master's thesis. The quality of the literature should be examined after four criteria that VIKO (support organization for information literacy) at NTNU has presented on their websites. These four criteria are credibility, objectivity, accuracy and suitability (Viko 2010). We have evaluated our literature in regard to these four criteria.

In our literature study, we started to design a excel sheet with different headlines to categorize literature after theory area, author, title, journal, book, citations, keywords, database/search engine, content and assessment. Then, we decided which theory areas that should be included in chapter two (theory and literature) on the basis of the research questions. We came up with the following theory areas - which has various sub areas with relation to the theory area:

- building types
- energy requirements
- calculation models
- monitoring and measurement of energy use
- management towards best practice
- user behavior in non-domestic buildings

Furthermore, now that we had an idea of what literature we wanted for the master's thesis, we began to search with Google Scholar, Scopus and BIBSYS's databases. BIBSYS is NTNU's database of the library, while Scopus is a large international abstract and citation database (Elsevier 2013). BIBSYS provides a good overview of the literature and articles in the library at NTNU, while Scopus extends beyond this and contain international publications. Google Scholar is a search engine for scientific literature (Google 2013). A combination of databases and search engines is important to do a thorough literature study to examine several areas. Scopus and BIBSYS gave good opportunity to put filters on the searches to achieve good relevance. Still, we were most pleased with the results that we got from Google Scholar where we mostly filtered using date. When it comes to laws and requirements, we have used Lovdata's webpages with support from other literature. Standards are from Standard Norge, which we have access to as students of NTNU. We also found publications made by SINTEF, Enova and NVE among others.

Google's search engine has been used supplementary when needed both for the literature study and for finding data for the two cases. In addition, our mentor; Dr. Antje Junghans has helped with advice on relevant literature from both her own and other studies.

We chose to divide the literature search according to the theory areas on the previous page, and conducted searches to find relevant theory and literature for each of them. A justification for the choices of theory areas is presented below.

Theory area 1 - Building types:

We have already defined what we mean by non-domestic buildings and that several building types is included in this term. We have chosen to emphasize what a building type is, and which building types that is included under the term of non-domestic buildings with a focus on this master's thesis. We see this as an important intro to the theory and liteature chapter in retrospect to the topic of this master's thesis.

Theory area 2 - Energy requirements:

We have chosen to present fundamental laws, standards and requirements for Norway, which is limits that real estate developers and managers must follow and relate to. These are limitations associated to construction, energy use and energy efficiency among others.

Theory area 3 - Calculation models:

We have chosen this theory area since it is central to explain how the expected energy use in non-domestic buildings can be calculated - both in the design phase and more importantly in the operational phase. This involves presenting theory about which models and methods that can be used.

Theory area 4 - Monitoring and measurement of energy use:

We have chosen this theory area to explain how buildings is being monitored, how energy is measured and what the basis for the performance of the non-domestic buildings are - which is an important aspect.

Theory area 5 - Management towards best practice:

Management of buildings is central for the master's thesis. We have therefore chosen to present an introduction to facilities management and how management is performed and organized in general. We chosen to present the theory of benchmarking and best practices, as well a focus on energy efficiency in management of buildings and methods that can be used to ensure and improve energy efficiency in non-domestic buildings. We have also presented theory about barriers against energy efficiency.

Theory area 6 - User behavior in non-domestic buildings:

We have chosen to present theory of user behavior related to non-domestic buildings. We feel this is essential as users and their behavior is an important topic in relation to energy use in non-domestic buildings.

3.3.2 Systematic selection method and -criteria

We have chosen to create a systematic selection method with criteria to select two good and relevant non-domestic buildings for a case study. We feel that the number of buildings in our case study should be above one to make sure that we can compare the selected case, but not more than two buildings to fit the time we have for this master's thesis. Two buildings should give us enough information and data, aswell as a possibility to compare the buildings with each other. The systematic selection method consists of five areas - these are:

- building
- construction
- energy
- management
- users

Each of these areas contains different criteria. The systematic selection method has a total of 12 criteria. Some of these are difficult to check without being in contact with different parties in regard to the buildings. To end up with two non-domestic buildings in the case study we have made a list of potential selection candidates (both buildings and associated organizations). We have created a model and a flow chart that displays an overview of the areas and the steps in the systematic selection method.

For a building to pass the criteria in the systematic selection method and to be selected for the case study of this master's thesis, it must satisfy all the 12 criteria. These 12 criteria helps to refine and limit the master's thesis and the case study. The first criteria ask if the building is a non-domestic building, which is essential since we do not want a building with residental purposes. We want to look at buildings that are located in Trondheim where we are stationed. We will mainly focus on one building at the time to conduct the case studies and interviews. We want to look at buildings that are older than two years and younger or equal then fifteen years. This means that the buildings have atleast two years of measurements and results, but they are also not too old in regard to requirements and quality. It is important to be aware of that buildings usually have a startup (break-in periode) to optimize the management, operations and use of the building towards, if possible, best practice. We will look at medium to large sized building, which has a usable floor space greater than 3000 m^2. We have set a criteria that buildings will be connected to district heating and that it will have a BMS that works. The buildings shall have atleast two years of historical energy figures, and has to have a gap between expected and actual energy use. The buildings will be managed by a separate dedicated management department and be monitored with an energy monitoring system (EMS). At last, we want a user intensity greater than 100 users each day. The users must be employees of an organization or business located at the building.

A model of the systematic selection method is presented in figure 11 below, and a flowchart is presented in figure 12 on the next page. Figure 11 is shaped as a circle and have five parts in different colors with related criteria. The criteria are numbered and the model begins with the area for building and carry on clockwise from there. The numbered criteria and the colors will match the flowchart, presented in figure 12. In the flowchart, we put question marks after each criteria with a response option for either yes or no. If only one criteria is not met on the building tested in the systematic selection method, it will be rejected and we try the next building on our list of potential buildings.

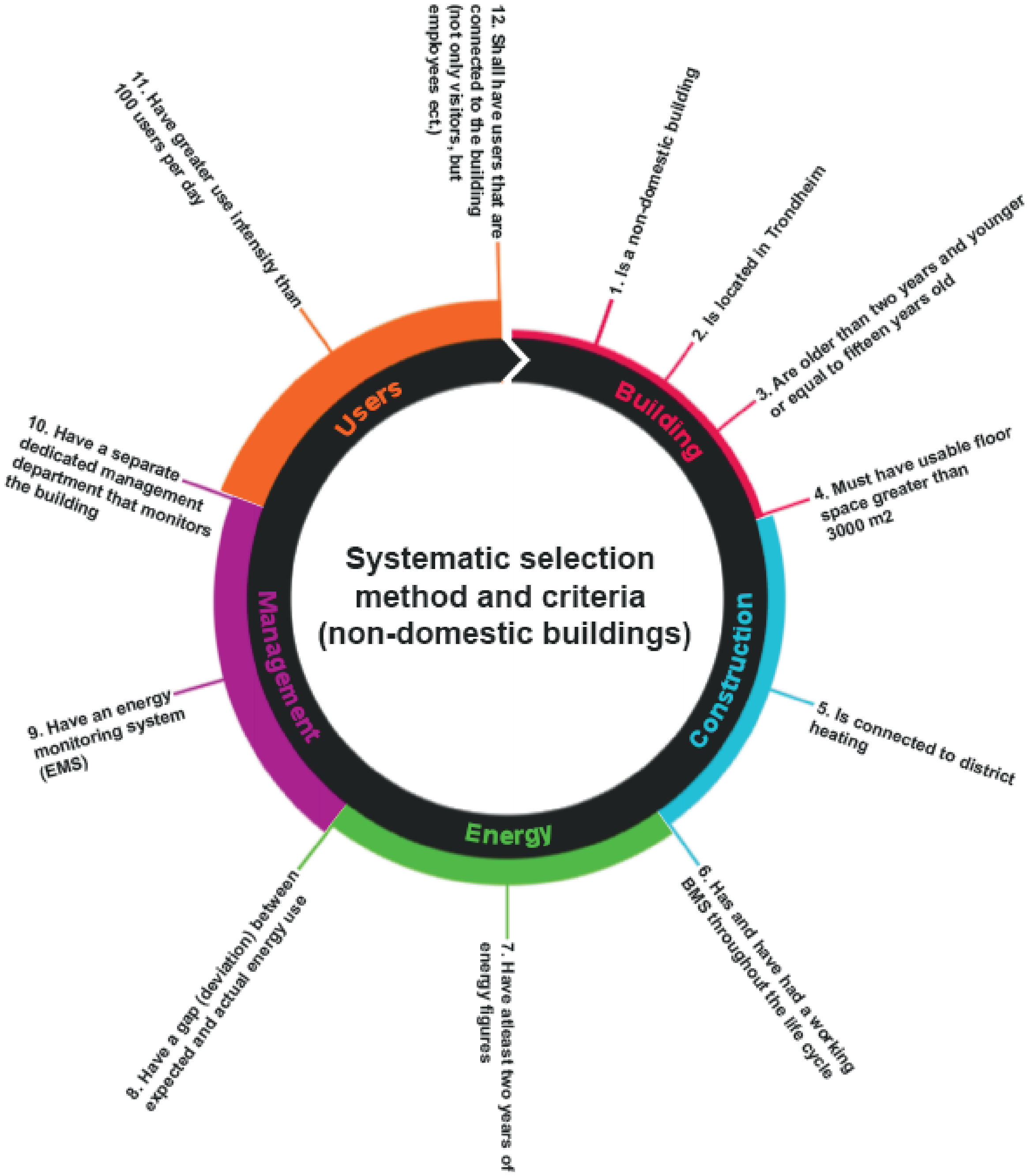

Figure 11 - Model: systematic selection method and criteria.

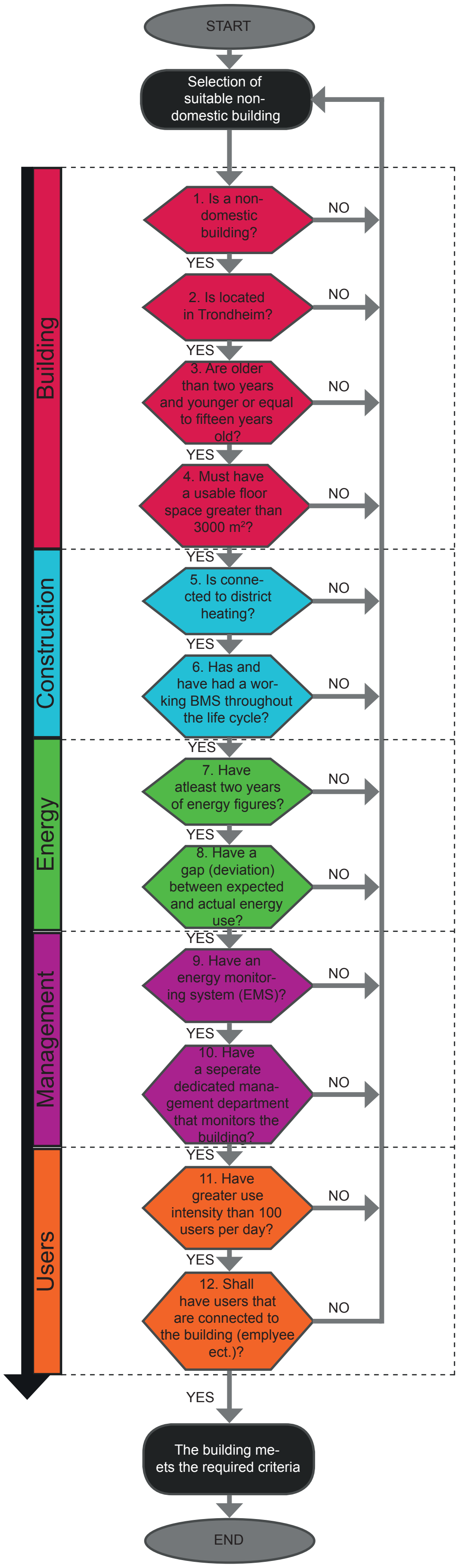

Figure 12 - Flowchart: systematic selection method and criteria

3.3.3 Case study

In chapter two we presented secondary data collected through a literature study. The case study aims to collect primary data - data collected directly from objects and respondents by the researcher (Jacobsen 2005). It will also be collected qualitative and quantitative secondary data in the form of necessary documentation, measured data and results in regard to the buildings. Primary and secondary data collected forms the basis of our results and findings, analysis and comparison, as well as the conclusion - directly linked to the purpose of answering the research questions and thesis question. A case study is one of several methods that can be used in a study to gather data (Yin 1994). A case study usually only have one or a few study units, such as one or two buildings. The selection of study units is carried out with a basis in analytical purposes (Halvorsen 1993). Case studies can consist of many different study units that may be delimited in space and time (Jacobsen 2005). A case study is often selected as part of the research design when the thesis question has query words like how or why - when phenomena in real contexts is examined in which the researcher har little control over the events that is studied (Yin 1994). According to Jacobsen (2005), case studies can be used when you want a deeper understanding of a specific event. In our case study we want to investigate two different existing non-domestic buildings that are selected through the systematic selection method that was presented section 3.3.2. As mentioned several times, we want to investigate the energy efficiency of existing non-domestic buildings through a focus on the gap between expected and actual energy use and management and use. We will present the buildings and take some photos to illustrate how the exterior and interior of the buildings looks. Plans and documentation will show an overview of the buildings. Our data collection of primary and secondary data will help describe how the building is or should be managed, operated and maintained - and how it is used or should be used. Which means that both the interviews and documentation will hopefully give us some insight into the management of the buildings and the users energy perspective and behavior. Measurements and energy readings will be read by the buildings energy monitoring devices through a BMS and EMS which makes us able to gather data and results on the buildings energy use and efficiency.

3.3.4 Data collection and -study

As we have mentioned earlier, we will collect primary data that is qualitative (words) and secondary data which is both qualitative and quantitative (numbers). To use various methods is called to combine methods, or more specified; method triangulation. Combining methods may provide a broad data base and a more secure basis for analysis and interpretation, while it also may cause the amount of data to become more time-consuming and harder to handle (Repstad 1993). The primary qualitative data for the case study is collected through interviews of different respondants. Respondants are both managers and users of the two non-domestic buildings. We hope that through the interviews, we can get a further explanation of the secondary qualitative and quantitative data we have collected about the two non-domestic buildings. The secondary qualitative and quantitaive data consists of existing documentation, reports and results that we have found or collected from managers, operators or engineering managers at the two non-domestic buildings, but also from other sources such as the web. This should include documentation of estimated and measured figures compared to what is expected of energy use, as well as numbers and results from actual operation and use of the building. The theory and literature collected through the literature study may also be described as secondary data. The secondary qualitative and quantitative data must be processed and quality controlled.

3.3.5 Interviews

A qualitative interview is a method used to collect the primary data in a study. This method of data collection is intensive, it means that there are few units (respondents) and many variables examined (Jacobsen 2005). We distinguish between two types of interviews; individual interviews and group interviews. These interviews may again have different degrees of structure, i.e. the extent to which the interview is controlled by a set of constraints in form of questions and response alternatives (Jacobsen 2005). We would like to conduct interviews with a medium degree of structure. This is interviews that are conducted using an interview guide - a guide with relevant headings and open questions, so that it is possible to get unexpected points of view. This is information you might not get from interviews with a higher degree of structure (Jacobsen 2005).

Qualitative interviews can be a difficult method to use to collect data. It is difficult to plan how long it takes to complete these interviews and this will often vary from respondent to respondent. An interview can last for around one to three hours, but also shorter or even longer. At one point during the interview, the interviewer may have sufficient information, then it is time to end the interview (Holme & Solvang 1996). All interviews will be transcribed if we get permission to use a tape recorder.

For our interviews, we want respondants that are managers (or operators) and users. We want to interview two to three managers or operators per building who is included in the daily management and operation processes of the selected building. It is desirable that respondants has a long relationship with building - to get an better overview of the development of the management and operation of the building over time. It is also important that atleast one of the management respondants is working in relation with energy. As for the user repondants, we would like to interview users who has been at the buildings for some time, and not a user who just started to use it. We feel that a user who has been a user of the building for some time might have a better input towards our master's thesis. The users will be connected to an organization who is located at the building. We want to interview two to four user repondants per building. We will find and select relevant respondants by contacting different potential respondents, asking a few simple questions to make sure that they are relevant for our interviews. This are questions about their relation with the building, how long their been managing it or have used it and what they do at the building and if they would like to help us by being a part of our case study be letting us interview them. After we have evaluated the potential users who is willing to be a part of our case study, we will agree on a date for the interview to be conducted.

To sum up, our case study will include two to three management respondants and two to four user repondants per building - eight to 14 respondents in totalt. The number of respondent will depend on how much information and input we get and how satisfied we are with that information. When we feel that we have gotten the right amount of necessary information we will stop, again bound to the minimum that we should have at least four repondents per building and eight in total.

3.3.6 Interview guide

An interview guide serves as a kind of framework for interviews. This framework should not be too controlled, but should have topics that the researcher sees as central to the study (Holme & Solvang 1996). We have created two interview guides, one aimed at managers (or operators) of the buildings and one aimed at the buildings users. The interview guides have thematic headings and questions as sub-sections. We have a presentation of us and an introduction to the master's thesis added in the start of the interview guides. We want to obtain a written consent from the persons we interview. In this concent we ask if it is okay for us to use a tape recorder and if we may add the trascribed interview in the appendix if it is appropriate for the master's thesis. This is also added in the start of the interview guides. We will not do any of this without the participant's permission. All the respondants will be anonymous in this master's thesis, and we will use their position title instead of their name. The interviews will be recorded on a tape recorder via a smartphone app which gives us the possibility to transcribe the interviews to ensure we do not miss important and relevant information. If respondants do not want us to use a tape recorder, we will refrain from it and take notes instead. Data collection must be based on the participants informed consent, i.e. those participating in the study do this voluntary, based on an assessment of risks and benefits of participating in the study (Jacobsen 2005). Our interview guides are added as attachments in this master's thesis appendix. The interview guides should be tested before they are used, this is to make sure they are optimized so that we may get the information we need for the case study.

3.4 Research quality

In this section we discuss various factors related to the quality of the method, research design and data collection. As we have written before, we have chosen to conduct a literature study based on the thesis question and research questions, and a case study of two selected existing non-domestic buildings what where selected through a systematic selection method. In the case study we will collect primary qualitative data (through interviews with a medium degree of structure) and both qualitative and quantitative secondary data (through documentation, measurements and results of the buildings, as well as external theory and literature to support the master's thesis). After the study is completed it is important to be critical of it (Jacobsen 2005). Is the study valid and reliable? The findings, analysis and conclusion are made on the basis of the primary and secondary data collection and study findings. You can evaluate the quality of a study if you are critical to the validity and reliability of the study (Jacobsen 2005).

3.4.1 Validity

Validity can be divided into internal and external. The internal validity will say something about if the discoveries that are made are perceived as correct and have a high degree of satisfaction towards the purpose of the master's thesis. The external validity will say something about if the findings may apply to other contexts - i.e. a degree of generalization. The validity of a study is dependent on what that has been studied, and whether the thesis question is desired clarified on the basis of it (Holme & Solvang 1996).

The internal validity is about if a phenomenon is described correctly (Jacobsen 2005). To test the internal validity, there are several methods that can be used. One method is to present the findings and conclusions made for those who have been studied (Jacobsen 2005) - in our case the buildings and respondents. This is done to examine whether the respondents recognize themselves in what is being presented (Jacobsen 2005). This method of examining the validity has not been performed. An other method to examine the validity is to control the study in regard to external theory, literature and empirism. The validity would be strengthened if it is equal contexts (Jacobsen 2005). This is partly performed through the literature study and the case study and conduction of interviews - through the analysis of the master's thesis. We can see that there is both similarities and differences. The internal validity of the master's thesis may be perceived as strengthened because of this. In relation to the internal validity it is also imporant to go though and be critical of the sources and the information from the sources (Jacobsen 2005). I this master's thesis our sources is a combination of theory and literature, documents, reports and results, and respondents interviewed. We think that we have selected appropriate and good respondents, which have managed to provide important insight and information. It can be discussed how specific and correct the conducted information is, especially in relation to the users of the buildings that have different behaviors and only constitute a small part of the overall organization(s) at the buildings. The theory and literature gathered can be argued to come from credible sources. The same applies to documents, reports and the results in relation to the buildings and energy use - as long as the energy monitoring devices are working properly. Information from severeal independent sources should support the validity of the study (Jacobsen 2005). We think that we have several credible sources in this master's thesis and that the validity is strengthened because of this. Both similar and different descriptions may strengthen the validity of a thesis since it is natural that people interpret and experience various circumstances differently. This is one of the main points of qualitative methods (Jacobsen 2005). Information in relation to the interviews will often be characterized by either being a reaction or a spontaneous statements by the respondent. The information which is a reaction based on a question from the researcher will often be described as a controlled response. The information based on the resondents own initiative will often be considered to have a greater validity since this is information that is not controlled by the researcher (Jacobsen 2005). Our interviews has both been characterized by our influence and the respondents own initiative.

As stated before, we want an exploratory study where we explain why or how something occurred - and how this can be changed. In relation to this the connections are important - to explain how one factor explains another. People do not always have an overview of all explanations. It can be discussed who has the best explanations (Jacobsen 2005). In relation with this it is important to try to identify different explanations from different sources (Jacobsen 2005) - in our case, respondents at different levels. People often percieve that one event leads to another, but it is important to be critical of the events, since the events not always are interrelated (Jacobsen 2005). Jacobsen (2005) writes that it is important to ask critical questions of the various explanations and events to investigate the relations and explanations, aswell as the importance of them. We think that we have had a critical relation to the different circumstances and explanations, and that by connecting them together through an analysis where these have been considered have supported the validity of the master's thesis.

The external validity is about the extent to which the findings and conclutions made can be generalized (Jacobsen 2005). This is not the purpose of the master's thesis, which is rather to highlight causes, possibilities and important aspects - to understand and elaborate concepts and phenomena. There are two forms of generalization, theoretical generalization and statistical generalization. Theoretical generalization is generalizing from data in a small range of objects to a theoretical level. Statistical generalization is to generalize the frequency of a phenomenon based on a small range of objects to describe a larger group of people (Jacobsen 2005). Our method, research design and data collection does not support the statistical generalization, especially because of the number of respondents, the choice of interviews, and the case study with two buildings. It is difficult and unlikely to imagine that these represent other buildings and people properly. Jacobsen (2005) writes that you can never be sure if you have got a representative selection of objects. Theoretical generalization may be possible based on our method, research design and data collection, but this will depend on if the findings are supported by other studies and research (Jacobsen 2005). If several studies from different contexts say the same, there may be an opportunity for generalization (Jacobsen 2005). We think that some specific factors in our master's thesis might translate two other context, but that our master's thesis is not intended or suitable for generalization.

3.4.2 Reliability

If a study can be regarded as reliable is based on whether we can trust the data that has been collected by the researcher (Jacobsen 2005). This is determined on the basis of how the data has been collected and how the data has been processed (Holme & Solvang 1996). To what extent is the reliability of the findings of a study been affected? This may for example be about a research effect that we wrote about earlier in the master's thesis, the research method or poor execution of the analysis (Jacobsen 2005).

All types of visible studies will expose the study objects of some form of signals and stimuli which the study objects responds to (Jacobsen 2005). There is a possibility of a research effect, interview effect or context effect. The research or interview effect is about the extent to which we influence the respondents, while the context effect is about how the context effect the respondents (Jacobsen 2005). It is almost certain that we have affected all those we have interviewed to some extent, large or small. We have written an interview guide so that the respondents in advance have an overview of the planned questions. This might be both positive and negative, since it enables the respondents to think through the questions and considered what they might say while they are alone. At the same time, the questions will also have some sort of effect on the respondents. In all the interviews we have also had several additional questions that may have controlled the interview in a direction. Although, we have tried to let the respondents have a opportunity and freedom to make their own and impulsive response.

Context effect can be divided into both artificial and natural, and planned and surprising. People often have different behavior in different contexts. Choosing a natural setting can help to reduce the context effects, but it may also be a greater potential for disruption in the natural contexts. Respondents' answers will also vary according to whether the interview is planned in advance or not. A respondent may respond differently in regard to this, but what is best suited can be discussed (Jacobsen 2005). To reduce the context effects, we have always been in rooms or areas that are known and common for the respondents. Yet, it is not common for respondents to be interviewed. All interviews was planned and scheduled in advance.

The reliability can also be influenced by the researcher's ability and accuracy in data collection, processing and analysis of data (Jacobsen 2005). We have been very specific when we have collected and evaluated all data collected in relation to this master's thesis. Everything has been systematically reviewed to ensure adequate and appropriate quality. Nevertheless, it is possible that there have been made mistakes. To reduce this possibility, all interviews were recorded and transcribed. All other data have been collected, systematized and evaluated. We feel that this may help to strengthen the reliability of the thesis. We have, throughout the master's thesis emphasized to describe and document what we are looking for, why we have chosen just that and where we have found it in regard to the data. The use of method triangulation have also ensured that we have shed light on the master's thesis through several methods and aspects.

3.5 Summery of research method

We will use references to specific sections in this chapter.

This master's thesis is performed based on a thesis question and three research questions. The purpose with the thesis question and research questions is to investigate energy efficiency through management and use of existing non-domestic buildings with a focus on the gap between expected and actual energy use. This is the basis for the applied method, where the thesis question has an intensive purpose with an explanatory direction (3.3).

There are several methods used to collect both primary and secondary data that can be defined as both qualitative (3.2.1) and quantitative (3.2.2). This can be described as method triangulation (3.3.4). Case study (3.3.3), literature study (3.3.1), interviews (3.3.5) with an interview guide (3.3.6) and data collection (3.3.4) is the main methods used, with the support of a systematic selection method and criteria to select the cases for the case study (3.3.2).

Both validity (3.4.1) and reliability (3.4.2) can be assessed as satisfactory and it have been several initiatives to strengthen the quality of the methods and study in the master's thesis, especially based on sources that have been used (3.4).

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Chapter 4

Presentation of cases and findings - from the conducted case study and related interviews

Picture 1 - Main entrance of Realfagbygget (Photo: Daniel R. Hansen).

Realfagbygget

Høgskoleringen 5, 7491 Trondheim

1. Is a non-domestic building?

Yes, university and college building, building group 62, building type 621.

2. Is located in Trondheim?

Yes, Høgskoleringen 5, 7491 Trondheim.

3. Are older than two years and younger or equal to fifteen years old?

Yes, opened 31 May 2000, 14 years old.

4. Must have usable floor space greater than 3000 m^2?

Yes, 40 000 m^2 usable floor space.

5. Is connected to district heating?

Yes.

6. Has had a working BMS throughout the life cycle?

Yes.

7. Have atleast two years of energy figures?

Yes, energy figures back to 2003.

8. Have a gap (deviation) between expected and actual energy use?

Yes.

9. Have an energy monitoring system (EMS)?

Yes.

10. Have a separate dedicated management department that monitors the building?

Yes, both a management department and a operation department.

11. Have greater use intensity than 100 users per day?

Yes, approximetly 3200 users daily.

12. Have users that are connected to the building (employees ect.)?

Yes, both employees, students and operation and maintenance personnel.

Picture 2 - Front facade of Miljøbygget (Photo: Daniel R. Hansen).

Miljøbygget (KLP-bygget)

Professor Brochsgate 2, 7030 Trondheim

1. Is a non-domestic building?

Yes, office building, building group 31, building type 311.

2. Is located in Trondheim?

Yes, Professor Brochsgate 2, 7030 Trondheim.

3. Are older than two years and younger or equal to fifteen years old?

Yes, completed November 2009, over 4 years old.

4. Must have usable floor space greater than 3000 m^2?

Yes, 13.100 m^2 for rental, and 3.300 m^2 usable floor space for basement parking and technical rooms.

5. Is connected to district heating?

Yes.

6. Has had a working BMS throughout the life cycle?

Yes.

7. Have atleast two years of energy figures?

Yes, energy figures back to 2011.

8. Have a gap (deviation) between expected and actual energy use?

Yes.

9. Have an energy monitoring system (EMS)?

Yes.

10. Have a separate dedicated management department that monitors the building?

Yes, are managed and operated by an organization.

11. Have greater use intensity than 100 users per day?

Yes, but users vary in regard to how much area that is rented out.

12. Have users that are connected to the building (employees ect.)?

Yes, both organizations, employees and operation and maintenance personnel.

4.0 Case study

In this chapter we will present the empiricism that we have conducted in regard to the tasks of the master's thesis. After trying several potential buildings with our systematic selection method and criteria we have ended up with two buildings fitted for our case study. The two buildings are Realfagbygget and Miljøbygget (also called KLP-bygget). On the four previous pages, we made an overview of the criteria, structured as questions and answered them to show that the buildings have passed the criteria and have been selected for our case study. We will present our findings, which is both primary and secondary data that we have gathered and can be defined as both qualitative and quantitative as we wrote in chapter 3. The primary data is the result of the interviews that we have conducted. We have conducted 12 interviews in total, seven in regard to Realfagbygget and five in regard to Miljøbygget. The secondary data is from documentation, reports and other sources such as the web. The chapter is structured so that we first present findings for Realfagbygget, then Miljøbygget. We have several sub-sections for each case where we first describe benefits and risks in regard to the selection. Further, the buildings are presented, then we present the energy use, gap and label. Finally, we present the findings from the conducted interviews.

4.1 Case - Realfagbygget

4.1.1 Benefits and risks

Realfagbygget is a building that we are users of almost every day. We are students who have used the building frequently over the past two years. For this reason there are both benefits and risks associated with this selection. The benefits related to this perspective is that we are very familiar with the building, we have contacts and possibly an easier access to both the building, people, organizations, help and support in regard to the case and our master's thesis. At the same time, this leads to a risk since we need to have a nautral posistion in relation to the empiricism - interviews and findings. We may not always agree with everything being said because we have our own experiences, expectations, needs and views in regard to both the management, operation and use of the building. We also recognize and agree with many factors that have been presented through the interviews and general data collection. This makes us both critical and partially agreed with the various aspects of the empirical data. Our challenge has been to stand as a neutral party for the empirical findings. The findings is based on our interviews, interview guide, choice of respondents and data gathering among other factors - the empiricism. We have tried to not steer the interviews too much, but have rather used the interview guide as a red line to stick to, where additional questions was asked from a neutral standpoint and in regard to the theory and literature. This is something we think we've managed well, but it will certainly be a degree of research effect as desribed in chapter 3.

An other risk factor we detected relatively early is that the buildings of NTNU (Norwegian University of Science and Technology) is poorly documented. There is little available documentation about Realfagbygget, especially in regard to a detailed and technical nature. We have tryed to the best of our efforts to get as much data as possible with help from the respondents. The building is 14 years old and is not built in regard to todays technical requirements (TEK 10). There have been many changes along the way, especially in terms of technical installations and systems. We have not been able to document what the building was expected to use of energy, based on the design phase, which is fine in regard to our focus on existing buildings presented in chapter 1. Since systems have been replaced and renewed, we have not been able to obtain energy figures for the whole life of the building. We have however managed to obtain energy figures back to 2003, through restoring older systems with the help of the operations department at NTNU. One benefit with this building is that it satisfies the category of existing building well. It is not so old, built modern and has been used and operated for 14 years. This makes it possible to look at the situation, particularly from an management and operational perspective. Students who began using the building is done with their studies long ago, we have still got to interview students who have been users for up to six years, and an employee who has been stationed in the building since 2001. There is still a risk in regard to the high amount of different users who use the building, which most certainly have different views, expectations and experiences, but we can not conduct them all, and have to base our findings on the respondents who we have interviewed.

4.1.2 Presentation

4.1.2.1 General description

Realfagbygget is one of the many buildings at the Gløshaugen campus of NTNU (Norwegian University of Science and Technology). Realfagbygget was opened on the 31st of May 2000. This is three years after the foundation stone was placed. The idea behind Realfagbygget was to gather the science subjects, which partly was located in different locations of the city of Trondheim, and to make a stronger integration of the professional activities (Statsbygg 2014a).

Realfagbygget is a large building, constructed on a relatively small site with a total of nine floors plus an additional technical floor on the roof. The building consists of 62 605 m^2 gross floor area (GFA) and approximately 40 000 m^2 UFA. The area consist of auditoriums, classrooms, reading rooms, cafeteria, canteen, teaching and research laboratories, library and offices among other areas such as areas for leisure, movement and operation (Statsbygg 2014b, Statsbygg 2014c, Universitetsavisa 2000).

The architecture at Realfagbygget shall express exploratory, enlightening and progressive qualities. The architecture has been a factor with a high priority. This is to establish surroundings that support and promote an intriguing place of study and the creation of ideas. The architectural form is strict, linear and rectangular - coordinated to meet

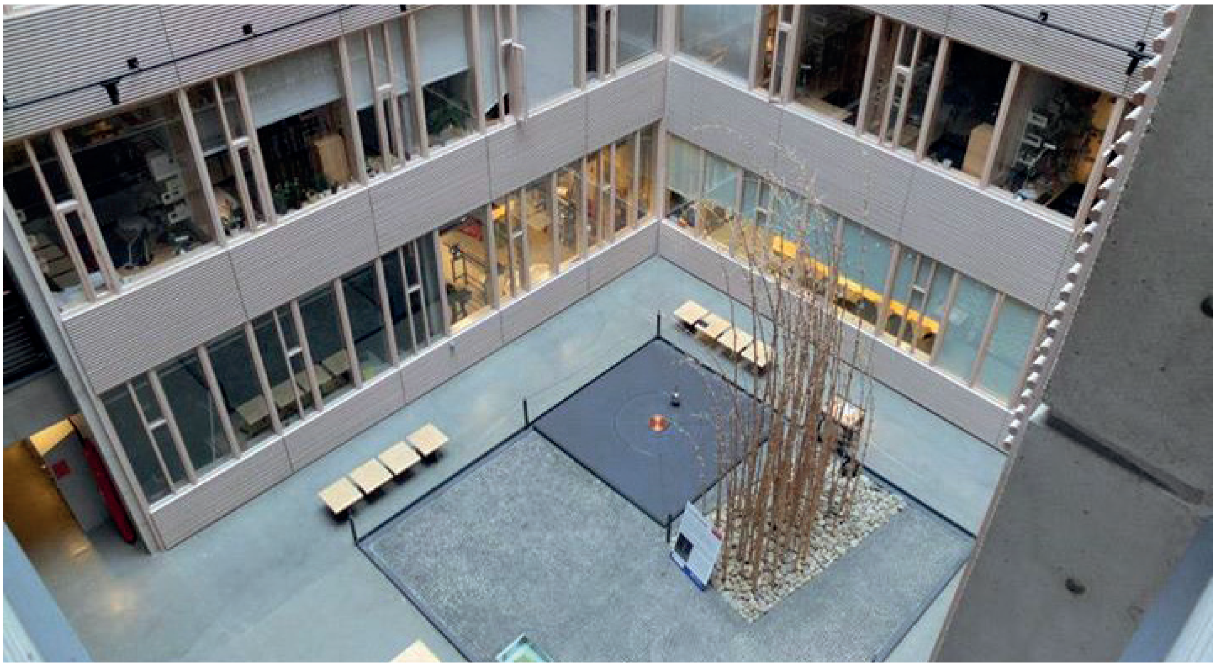

Picture 3 - Main communication axis in the first floor (Photo: Lars A. K. Jørgensen).

and embrace the environment. Realfagbygget is connected to older chemistry buildings which has affected the the design and structure. The architectural principles are resolved through shades and variations related to the building construction (Statsbygg 2014b).

Realfagbygget has been decorated with art based on an idea to address a link between science and humanities - the result is a crossing point between ornate artists and the scientific community. There has also been composed a set music pieces which is put together randomly and played occasionally based on a computer program that consider the wind, weather and heat sensors. The music is played through 32 speakers. The idea is to create an exciting and vivid environment, which are not a nuisance for the users (Statsbygg 2014b, Universitetsavisa 2000).

The common areas of Realfagbygget is split on each side of a transversal axis, a main internal communication that bridges from the main access zone, the entrance in the east and goes west through the building to a 90 degree bend down towards an other access zone, a entrence in the north. The main communcation axis is shown in picture 3 above. On each side of the axis there is auditoriums, reading rooms, a library, cafeteria, canteen, leisure areas, stairs, elevators and corridors down to teaching and research areas, office areas, laboratories and technical rooms. A leisure area is shown in picture 4 on the next page. There are technical areas organized as individual and open units on the roof, connected to technical rooms. This solution attempts to give a high-tech expression of the building and is also an active part of the building (Statsbygg 2014b).

High user frequency functions are located on the first floor and in the first basement floor (U1). These functions are attached to the main communication axis described abo-



Picture 4 - Leisure area taken from the first floor (Photo: Lars A. K. Jørgensen).

ve - working like a main street through the building. The functions are accessed through the main entrance on the first or through other desentralized entrances connected to the functions. Other functions is also connected to this axis on different levels (Statsbygg 2014b).

An information and monitoring section is located on the first floor close to the main entrance. The faculty offices is located on the first floor, and can be located and accessed from the main communcation axis near the main entrance. The institutes is located from the fifth floor, down to the third basement floor. Their location is based on function and student frequency (Statsbygg 2014b). There is a canteen for employees, students and visitors which contains 450 seating places, located on the first floor where the axis bend 90 degrees. The canteen has access to an outside terrace and an overview of the city of Trondheim. A small cafeteria is located in the first basement floor, below the main entrance. The cafeteria has access to an outside terrace facing south (Statsbygg 2014b).

The library is located on the first floor and the first basement floor, with entrance from the main communication axis close to the main entrance of the building. The library is a shared library for the science subjects (Statsbygg 2014b).

Realfagbygget has nine auditoriums. All of them is accessed from the first basement floor. The reading rooms is mostly located on the first floor with access from the main communcation axis and close to the library. There are many reading rooms of different sizes. There are group rooms and meeting rooms of smaller size available to the users of the building, which are located on almost all floors of the building (Statsbygg 2014b).

Realfagbygget has several computer rooms and laboratories, which is located in the first and second basement floor (U1 and U2) with access from the main communcation axis. There are several workshops located at Realfagbygget - both for metal, glass, wood, electronics and computers. The metal, glass, and wood workshops are located on the third basement floor (U3). The electronics and computer workshops is located on the second and third floor (Statsbygg 2014b).

Techincal rooms is located in the forth basement floor (U4) and include rooms for uninterruptible power supply, reserve power, tranformers, switchboard, cooling and heating plant, and telephone and telematics central. There are also ventilation rooms placed in the basement and on the roof. Storage is placed in the institute areas and in the dark zones of the building - more specifically in the second, third and forth basement floors (Statsbygg 2014b).

4.1.2.2 Address

The address of Realfagbygget is Høgskoleringen 5, 7491 Trondheim.

4.1.2.3 Localization

Realfagbygget is correctly located in Norway, Sør-Trøndelag, Trondheim, Gløshaugen, Høgskoleringen 5, 7491 Trondheim. Figure 13, 14 and 15 in the next column shows the location and orientation - north is up.

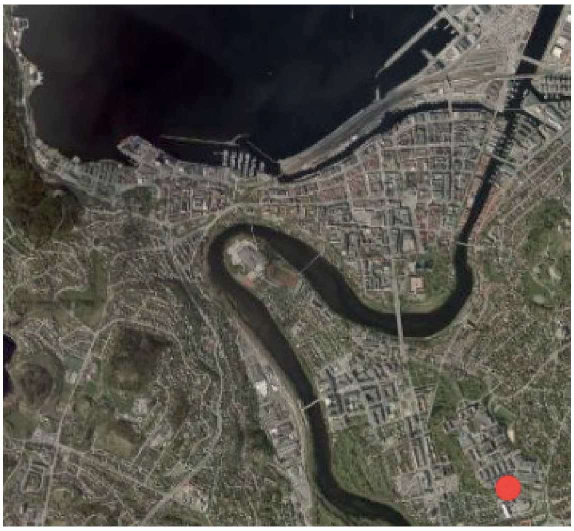


Figure 13 - Trondheim (FINN kart 2014).

Figure 14 - Campus Gløshaugen (NTNU) (FINN kart 2014).

Figure 15 - Realfagbygget (FINN kart 2014).

4.1.2.4 Floor plans

Figure 16 below show the floor plan for the first floor at Realfagbygget - with different colors and letters for the different building blocks which is commonly used at Realfagbygget, according to the respondents. We have added additional floor plans for Realfagbygget in the appendix. The floor plans support the descriptions about the building aswell as the interviews to get a better overview and understanding of the case study.

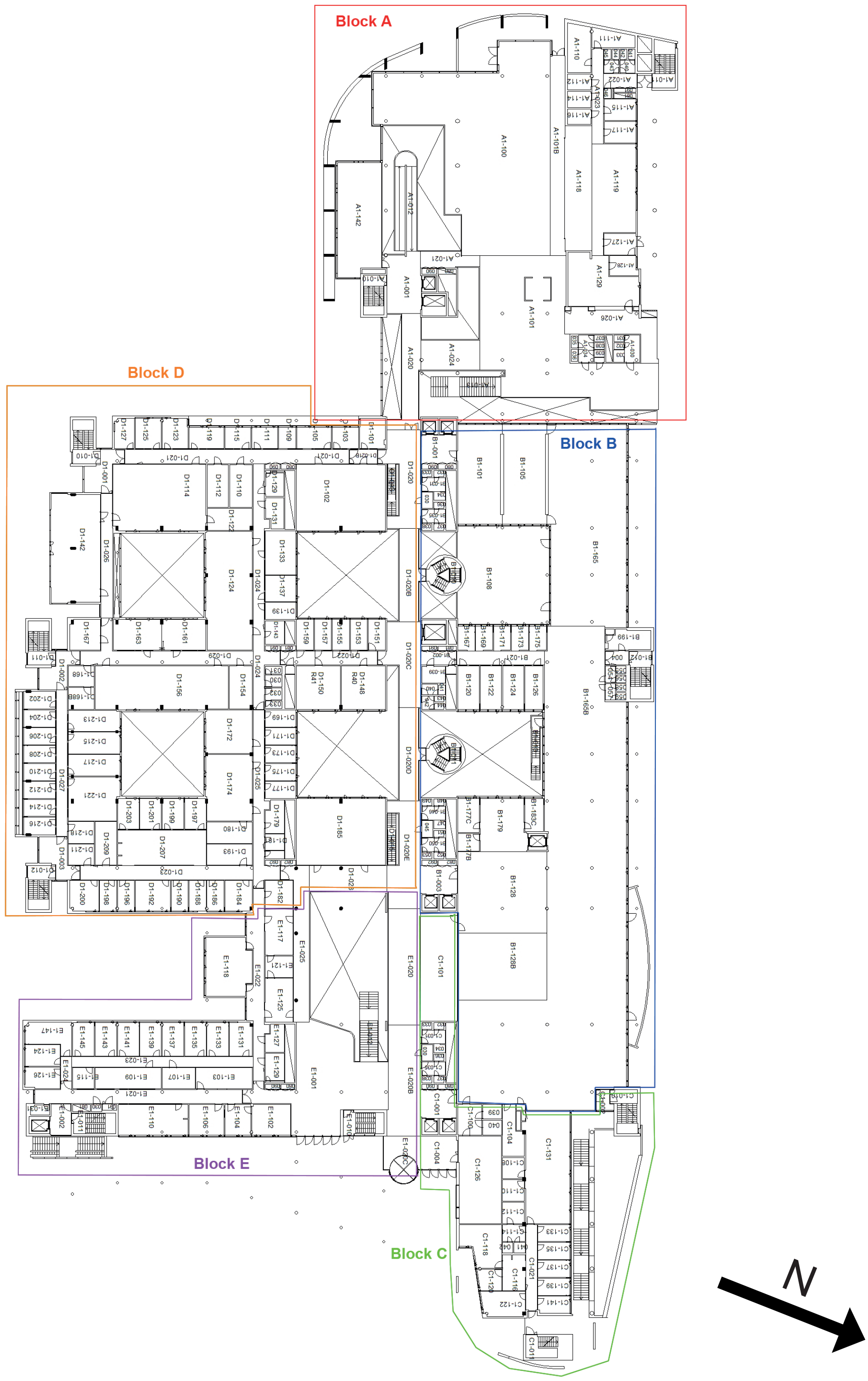


Figure 16 - Edited floor plan of the first floor at Realfagbygget (NTNU 2014a).

4.1.2.5 Project costs

Total project costs was approximately 1 310 600 000 NOK which gives 20 934 NOK per m^2 GFA (Statsbygg 2014c).

4.1.2.6 Building technical

The facade construction on the exterior is characterized by extensive use of white place molded concrete and the use of glass. The main wings are covered with a white-yellow travertine and is attached on rails. There is used untreated teak on frames, window elements, openings and on recessed walls of the white concrete surfaces. The wood is used to bind the components together. The transverse blocks are treated with a combination of rust red, yellow and earth colored plaster. There is also used a proportion aluminum as fixed shading devices (Statsbygg 2014b).

The inside of Realfagbygget is also characterized by the use of white place molded concrete, which have the same pattern as the exterior, but it is more dust treated and hand sanded. The walls of the corridors in the main wings is painted with different colors, a factor that continues throughout the building. The ceilings are constructed with aluminum rails and covered with wood in auditoriums and classrooms. The library, teaching areas and corridors has a linoleum flooring, while laboratories has a homogeneous vinyl flooring. The canteen, the podium in the auditoriums and some group rooms has oak floors. The walls of the main communication axis and canteen has walls of wood and concrete (Statsbygg 2014b).

Realfagbygget has large areas dedicated to technical installations to support the large building. There is installed around 90 different ventilation systems. Lighting is controlled through a central, while common areas are installed with light sensors (Universitetsavisa 2000). In regard to a respondent, district heating and electricity is used for heating through heat pumps, heat recovery and ventilation. Cooling of the building is done by means of ventilation and pumps. The building is equipped with radiators in several areas and rooms. This year it has been installed ammonia pump that both support heating and cooling of the building in regard to the respondent. The building has three BMS that control the technical installations, while a EMS keep an overview and control of the energy performance through 400-500 energy monitoring devices, based on a respondent.

4.1.2.7 User technical

Realfagbygget has many different users, which has different needs of technical equipment everyday. Students has reading rooms, group rooms, auditoriums, a library, computer rooms, labratories, workshops available with related equipment to each room. There are computers available in some rooms such as the computer rooms and in the library. There is power outlets available in most rooms to support the use of a laptop or other devices. Most teaching rooms and some group rooms are installed with projectors or screens. There are also computers available to guests and visitors. Some rooms have installed radiators and light switches, while other rooms and areas, especially common areas has sensors.

Room temperature is mainly set by the operating personnel, but may be affected by use of the radiators and window where that is a possibility. Most of these windows open to the indoor enviroment of the building rather than the out side environment. Employees and staff use different office rooms, meeting rooms, printing and office equipment rooms and common areas. A general office room is equipped with a computer, phone, radiators and has a window which may be opened. The possibility to open a window to the out door environment has been changed at the request of users. There are also windows that open to the indoor environment. Room temperature in these areas is mainly set by the operating personnel, but may be affected by use of the radiators and window. There are of course various chairs and tables other furniture placed in the different rooms for the different users and functions. It installed several elevators of various sizes in the building. All this is based on the respondents.

4.1.2.8 Owner

Accordring to a respondent, NTNU had a technical department, which was split into a property management deparment and a operation department in 2009. Realfagbygget is owned by the property management department at NTNU.

4.1.2.9 FM organization

As stated above, NTNU has two departments with different tasks in regard to the management, maintenance and development of Realfagbygget. The operation department has the responsibility for the on going maintenance, day-to-day operation of the building and energy monitoring. The property management department has the responsibility for the general management, development and other maintenance. The difference between the departments is mainly the day-to-day focus (operation department) and the long-term perspective (property management department) (NTNU 2013).

4.1.2.10 Users

Realfagbygget is a building of the Gløshaugen campus of NTNU. NTNU is short for Norwegian University of Science and Technology and has the main responsibility for the higher technology science eduaction in Norway, with the addition of medicine, architecture, arts, humanities, social sciences, humanities and teacher education (NTNU 2014b).

NTNU has around 23 000 students, where 2 600 students come from abroad. NTNU has approximately 5 000 full-time positions where the proportion directed towards teaching and research is around 3 000. NTNU concists of seven faculties and 48 institues (NTNU 2014c). Departments and sections located in Realfagbygget is a division of study administrative support, a IT division, the examination office of NTNU, the NTNU library (natural science library), a industrial ecology programme, the faculty of natural sciences and technology, the department of biology, the department of physics and the department of chemistry (NTNU 2014d). Operating and maintenance personell with responsibility for Realfagbygget is also located at Realfagbygget. Realfagbygget has many different users, students, staff, employees, operators, janitors, cleaning and maintenance workers, guests and visitors. There are also external service providers who come to the building for repairs on technical installations among others. The end user at Realfagbygget are mainly the students, staff and employees. There is approximately 3200 users daily at Realfagbygget. All this is based on the respondents.

4.1.3 Energy use, gap and label

4.1.3.1 Expected energy use

We have not found any documentation on how Realfagbygget was expected to performe in regard to any estimates of energy use from the design or constrcution phase. Through our interviews, we found out that expected energy use for Realfagbygget is calculated based on the average of the energy use for the three last years without the use of temperature correction. We will use the same calculation method. Findings from the interviews are presented later in this chapter. We have acquired energy use figures back to 2003, and will calculate the expected energy use from 2006 to 2014. Table 4 below show expected energy use for each year. In figure 17 below is a graph showing the development in the expected energy use from 2006 to 2014. The numbers used are based on electricity and district heating figures.

Year	2006	2007	2008	2009	2010	2011	2012	2013	2014
Expected energy use [kWh]	16652635	16558110	16676305	16252028	16068252	16714064	16901326	17129138	16194940

Table 4 - Expected energy use for Realfagbygget.

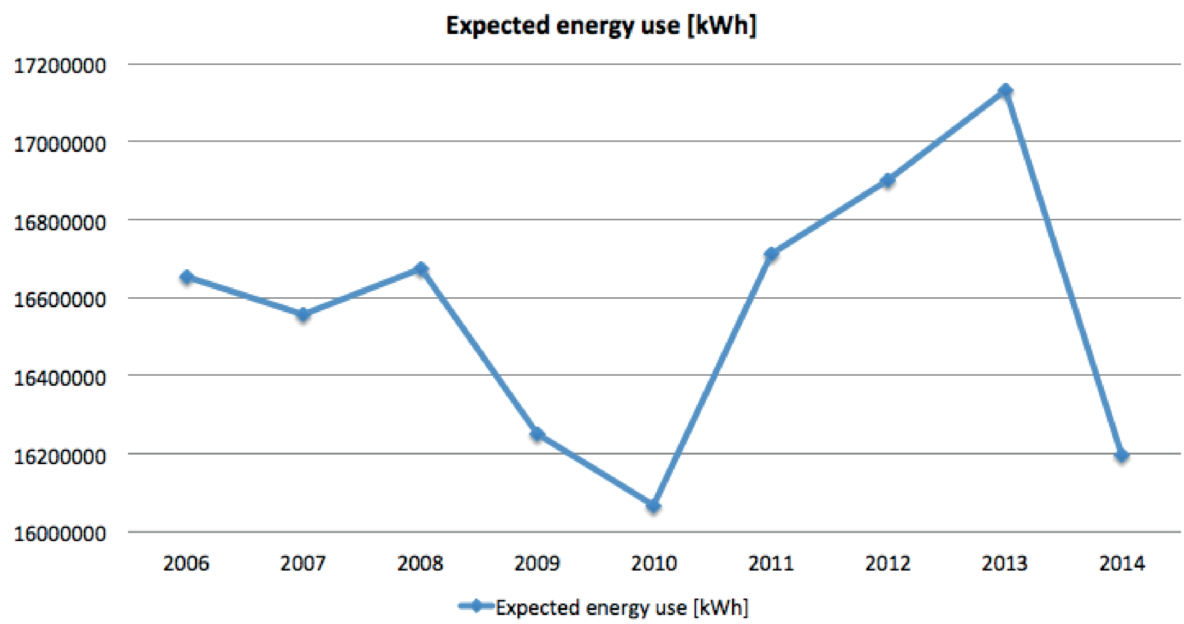


Figure 17 - Expected energy use for Realfagbygget.

4.1.3.2 Actual energy use

The actual energy use at Realfagbygget is data measured with energy monitoring devices attached to the technical installations and gathered with a EMS through the BMS, according to the respondents. Table 5 below show the actual energy use for each month and year. Table 6 show the proportion of electricity use for Realfagbygget. Figure 18 below show a graph for each year and the energy use per month. In figure 19 on the next page is a graph showing the development in the actual energy use from 2003 to 2013. The numbers used are based on electricity and district heating measurements and figures.

Month	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
January [kWh]	2071955	2097015	1639900	1738070	1932645	1816535	1640545	2210385	1764114	1954661	1880878
February [kWh]	1748730	1753695	1699070	1654155	1957735	1664470	1633245	1951355	1730209	1660404	1658552
March [kWh]	1633270	1603535	1710640	2021995	1514360	1661445	1342900	1746385	1646820	1435811	1743647
April [kWh]	1320615	1196810	1281200	1276905	1307505	1273505	1107660	1396250	1274839	1415655	1329099
May [kWh]	1271985	1117530	1213415	1196820	1203655	1097175	1023235	1272965	1110397	1204030	1082446
June [kWh]	1037555	988255	1086220	1092685	1040640	924335	953665	1077715	884630	1041153	949004
July [kWh]	991005	873385	1019700	1000545	924640	844400	939510	992620	925188	959160	904761
August [kWh]	995825	1013550	1188770	1076125	1021440	849275	1012800	1084525	999827	1015533	975642
September [kWh]	1106030	1128200	1130345	1114980	1148765	971245	1135385	1256275	1051716	1100175	1032198
October [kWh]	1409835	1325660	1307560	1373555	1365350	1206735	1562317	1496220	1282723	1389322	1300594
November [kWh]	1569440	1742270	1477475	1521780	1708385	1407800	1605660	2065350	1382379	1458455	1564790
December[kWh]	1643825	1721090	1842545	1448880	1790460	1607090	2008245	2302970	1832955	2014243	1628810
Actual energy use [kWh]	16800070	16560995	16596840	16516495	16915580	15324010	15965167	18853015	15885797	16648602	16050421

Table 5 - Actual energy use for Realfagbygget.

Year	2006 [%]	2007 [%]	2008 [%]	2009 [%]	2010 [%]	2011 [%]	2012 [%]	2013 [%]
Proportion of electricity	68,28	64,69	70,94	71,18	62,29	74,80	69,77	71,69

Table 6 - Proportion of electricity use for Realfagbygget.

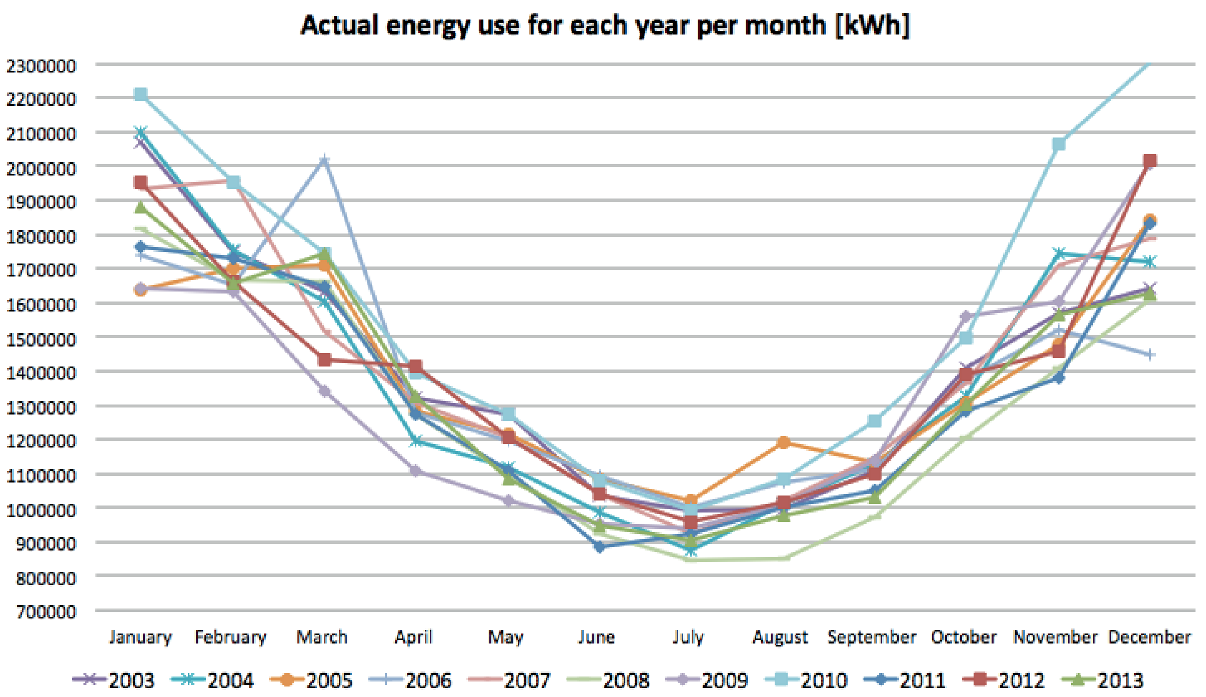


Figure 18 - Actual energy use for Realfagbygget per month.

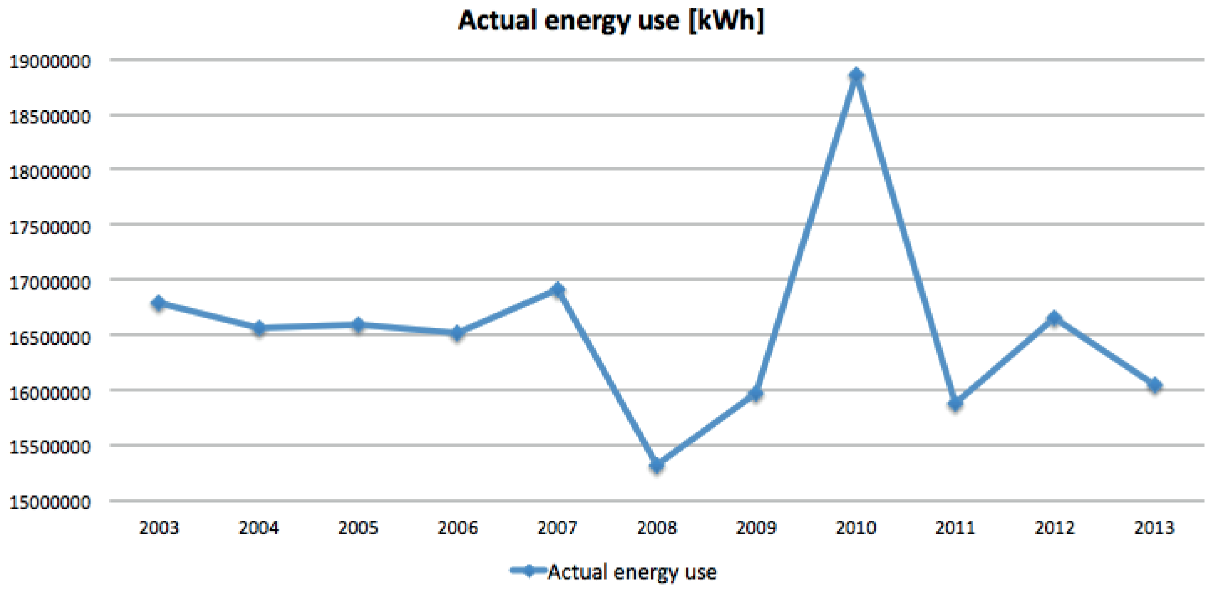


Figure 19 - Actual energy use for Realfagbygget.

4.1.3.3 Gap

By comparing the calculations for expected and actual energy use it is possible to calculate the gap. Table 7 below show the gap between expected and actual energy use. Figure 20 below show graphs for the expected and actual energy use - illustrating the gap.

Year	2006	2007	2008	2009	2010	2011	2012	2013	2014
Expected energy use [kWh]	16652635	16558110	16676305	16252028	16068252	16714064	16901326	17129138	16194940
Actual energy use [kWh]	16516495	16915580	15324010	15965167	18853015	15885797	16648602	16050421	
Gap [kWh]	136140	-357470	1352295	286861,33	-2784763	828267	252724,33	1078717	

Table 7 - Gap between expected and actual energy use for Realfagbygget.

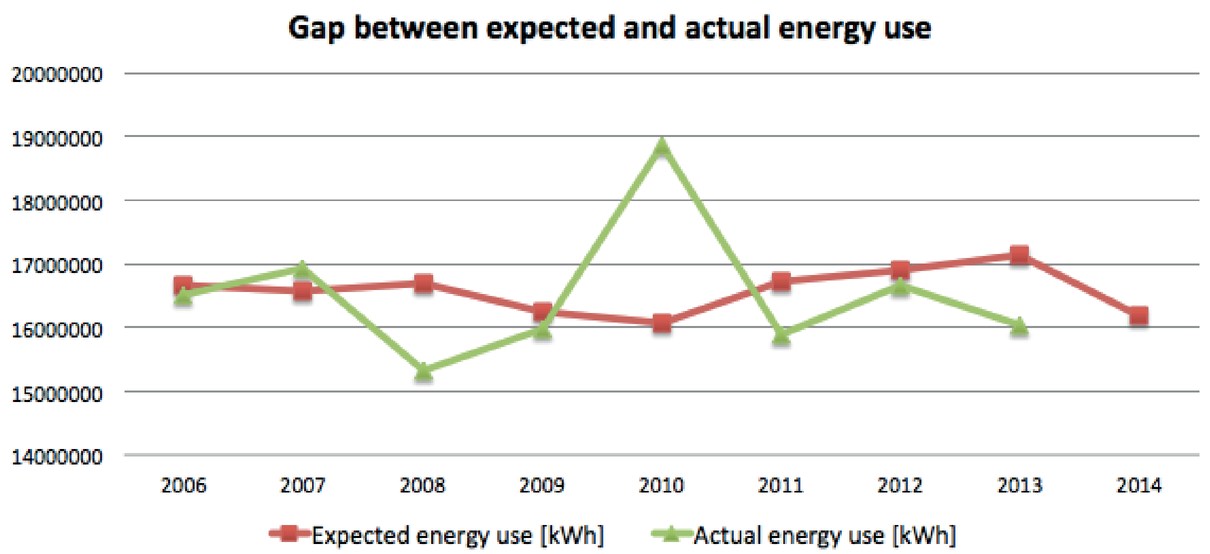


Table 20 - Expected and actual energy use for Realfagbygget.

4.1.3.4 Energy label

According to a respondent, Realfagbygget has not been energy labeled yet, but NTNU has a aims to energy label one building per year.

4.1.4 Interviews of facilities managers

In this section, the data and findings from the interviews of the facilities managers at Realfagbygget are presented. The section is structured based on the interview guide with the theory and literature chapter in mind. We start with the respondents (anonymously) to present their management profile, then go into the organization, management and tasks, calculation and measurement of energy use. Finally, we present their evaluation of the building. The citations is translated from norwegian to english by us with a focus to render as correctly as possible.

4.1.4.1 Respondents

We have interviewed three facilities managers of Realfagbygget. The interviews were conducted between the 4th and 22nd of April. Of the three respondents, one is a operation chief, one is a operation manager and one is a site manager.

The operation chief is an employee of the operation department at NTNU and is not stationed at Realfagbygget. A general day varies, but mostly consists of management and strategic planning processes in regard to the buildings of NTNU, often through meetings and conversations. There is also other administrative tasks included every day. The operation chief is educated as a marine engineer - which the respondent describe as a leadership education. The operation chief has been a facilities manager of Realfagbygget since 2009, has worked as a facilities manager since 2002 and has had leadership positions since 1980.

The operation manager is en employee of the operation department at NTNU and is not stationed at Realfagbygget. A general day varies between operation and monitoring tasks in regard to the BMS and EMS, while also develop and consider measures and possibilities in regard to both Realfagbygget and all the other buildings at NTNU. The operation manager is initially educated as an engineer and have worked with building automation since 1980. The operation manager started to work as a facilities manager in 1994, when the respondent was employed at the technical department at NTNU. The emplyee has worked as a facilities manager in regard to Realfagbygget since it was constructed and ready for use in 2000. The respondent has had the current position as a operation manager with the responsibilities in regard to building and energy management since 2009.

The site manager is an employee of the operation department at NTNU and is stationed at Realfagbygget. A general day varies between supervision and responsibilities for the operation of technical systems, mainly through operation and maintenance. The site manager is certified within the area of HVA-

C. The site manager has been a facilities manager of Realfagbygget since 2004, and has had the same position the whole time. The respondent has worked within management and operation of buildings since 1994.

4.1.4.2 Organization

The management and operation of Realfagbygget and the other buildings of NTNU is split between a property management department and a operation department. The property management department is the owner of the buildings and has the responsibility to manage, develop and maintain the buildings form a long-term perspective. The property management department also manage rental administration, internal renting and all costs. The property management department consists of 12 employees. The operation department has the responsibility for all operation tasks, cleaning, janitoral services, mail, park, transportation, building security, issuance of access cards among other services. Everything is in-house, according to a respondent, expect for specific repairs and construction projects. The operation department consists of about 350 employees. The property management department and the operation department at NTNU is located in the same building, close to Realfagbygget.

The main structure of the management and operation at NTNU is the the division of property management department (staff) and the operation department. The operation department is structured around a section of operations and logistics, and a section of craft services and building security. The section of operations and logistics is devided between operating areas (campus areas);

- Gløshaugen (north, middle, south)
- Dragvold
- outer areas
- park, transport, postal
- NTNU Printing

The section of craft services and building security is devided between disciplines;

- building
- HVAC
- electro
- building security

Realfagbygget is within the operating area of Gløshaugen south, where there is a operations manager for the operating area, and building manager and a site manager for Realfagbygget. The building manager has the responsibilities of the janitorial and cleaning services, while the building is controlled and monitored by the site manager. The operation department also control and monitor the building from the external management and operation building as a main support with a focus on tuning and energy monitoring. It is mainly the operation chief who is the respondent who has the best overview of the whole organization and structure, while the two other respondents mostly has an overview of the organization structure close to them, like who they report to and their responsibilities and tasks.

4.1.4.3 Management and tasks

The responsibilities and tasks are different between the three respondents interviewed. The site manager is stationed at Realfagbygget, while the two other respondents are stationed at an external building close to Realfagbygget and at the Gløshaugen campus. For the respondent stationed at the building, the tasks revolve operation and maintenance specifically for Realfagbygget and of the technical systems. This is mainly done through the BMS and other monitoring and control systems. The respondent also have some tasks to manage and follow-up external contracted companies which is at the building to preforme services or repairs. This is mainly measures that are needed and identified during an annual inspection. There are also measures that are reported through a system called Lydia. *"We use a system called Lydia, where we have measures and periodic measures to carry out"*, the respondent told us. Lydia is a system where all the users or employees can report cases and measures. The cases and measures are graded by priority. Since it is such a large building with many different technical installations, there is often unexpected cases that must be handled, according to the respondent. *"Realfagbygget is a building in continuous development and gets new technication installations that require tuning and monitoring, especially in the recent years"*, the respondent told us.

The operation chief is stationed at the external building mentioned, and has the main responsibility for operation and maintenance of all the buildings of NTNU, around 580 000 m^2. *"Everything is basically managed and operated from here"*, the respondent told us. A general work day for the respondent, revolves around meetings. The respondent has a staff to support with matters and administrative tasks.

The operation manager is stationed at the external building has the main responsibility in regard to control and monitoring the buildings of NTNU with a focus on the BMS and the energy monitoring through a EMS. A general day mostly consists of monitoring the buildings and energy performance, tuning the technical installations and correct deviations. The respondent also develop potential measures to improve and optimize the buildings, both as individual buildings and through the connection the different building has.

Their vision is; *"to be the most attractive and preferred supplier of NTNU's operation, maintenance and service tasks"*, a respondent told us. They have several goals, which was presented by a respondent. The objectives that were presented were to be an independent, responsibility conscious and positive staff. To have a systematic analysis of costs and resource use per building. To strengthening the expertise in corporate governance, and to strengthen the customer or user understanding and ability to have a needs-oriented communication. To have satisfied employees, avoiding work-related illnesses or injuries resulting from work tasks. No one who stay on campus shall be at risk for injury. Finally, they shall also increase the proportion of environmentally friendly solutions, have an organization that takes responsibility and develop initiatives for a sustainable university. To achieve this they shall implement measures to complement operation and maintenance plans and establish building accounting. Ensure that processes and solutions are based understanding and to support NTNU's primary and core activities. Develop effective working methods and rutines. Develop arenas, systems and skills that help to reveal the various customer needs the best way possible. Develop understanding and confidence for ongoing development. To establish energy saving efforts and reduce waste. Finally, they shall develop attitudes about environmental awareness and social responsibility within the organization. This is mainly based on the operation chief, while the other respondents generally refer to their responsibilities and tasks. *"We are a relatively large organization who work hard every day at different levels to ensure that Realfagbygget has good conditions and is operated and maintained sufficiently"*, a respondent told us.

"There has been a development and change in regard to how Realfagbygget is managed, operated and maintained", a respondent told us. A technical department was devided into property management and operation in 2009. Realfagbygget now has specific employees with responsibilities of the building, for the technical operation and maintenance, and for cleaning and janitoral services. *"This is something that has given a better overview of the various aspects, but we need to change and develop further"*, a respondent told us. The respondent indicate that there is a need to change the functions of the property management department and the operation department. The property management department is too operational and should have a strategic ownership of the buildings of NTNU instead. *"More like building portfolio management"*, the respondent suggested. The respondents feel that the operation department is ready to take over some of the operational responsibilities that the property management department have today, especially the project management. *"They should plan the development, while we should carry it out, today this is not so defined that it should be"*, the respondent told us. An other respondent refers to the management, operation and maintenance documentation, which they shall relate to in regard to Realfagbygget. *"There have been developments and changes of both the building and technical installations. There is more users and a need for densification and rebuilding"*, the respondent told us. These changes require tuning and optimization of the building and makes the documentation outdated to some degree, the respondent indicate.

To work towards best practice the operation department is conducting something they call comparative development - also called benchmarking. *"The purpose is to compare us to develop ourselves to be better"* a respondent told us. *"At the same time, we can defend that it is best to have a in-house solution in regard to management, operation and maintenance"*, the respondent continued. The benchmarking is performed with support for the consulting firm Deloitte. Through the benchmarking, they have found that they are too volunerable in regard to finding parameters, figures and numbers in regard to the buildings, operation and maintenance. *"We do not have good enough building accounting"*, a respondent told us. This is something they are working with to provide a better overview of what is happening and performed in relation to the buildings. To achieve this every employee has to invoice performed tasks at a detailed level. The respondents also say that there is a strong focus on indentifying skills, training and education and to develop, educate and train the employees. "*We have good follow-up of employees, education, norwegian language courses and computer training"*, a respondent told us. There is also a pilot project where the cleaning employees use an iPad to to control and registries the process of conducted cleaning. Still, there is an improvement area in regard to communication between people - both staff and students, management, operation and customers. There can also be better communication between the property management department and the operation department, according to the respondents.

The respondents think that NTNU is moving towards being a self-sustaining campus with their own high voltage system and buildings that are connected with each other to make the best possible us of energy and to reduce energy losses, while at the same time they have a full range of in-house services, management, operation and maintenance. *"I feel that Realfagbygget is monitored and tuned continuously, but there is still a potential for futher improvement"*, a respondent told us. A respondent also mentioned that they are trying to implement more automation of Realfagbygget, which is demand controlled. This is to reduce the energy use of unused rooms and areas. *"There is also a challenge to integrate new installations against the old"*, a respondent told us. A respondent also mentioned that they are trying to estimate the future in terms of study; *"we are trying to find out how the students want their everyday as students in relation to campus, area and lectures"*. A respondent suggests, based on trend researchers and student feedback, that there is more use of open and common areas, such as the canteen, and that the student environment on campus is moving towards a social meeting point.

4.1.4.4 Calculation of energy use

To calculate the expected energy use there is not developed any energy use budgets for management and use, but the facilities management of Realfagbygget use historical figures, the average energy use from the last three years, as an indication of the expected energy use. *"We use actual energy use from the last three years to calculate the expected energy use, actual energy use is data gathered in our energy monitoring systems"*, a respondent told us. Temperature correction is not performed. There are however developed energy budgets in regard to possible investments if there is new installations that are considered, and how the installations will contribute to a reduction in energy use. There is a daily review of the energy use. *"We are really interested in reducing energy use and have put together an energy conservation group"*, a respondent told us. It is the operation department that carry out the calculations for expected energy use for each year. This is done by gathering the energy data in the EMS and Excel is used for calculations and analysis. None of the respondents knew how Realfagbygget was expected to performe in regard to energy use.

4.1.4.5 Measurement of energy use

To monitor and measure the energy use at Realfagbygget, there is installed between 400 and 500 energy monitoring devices in the building which read the energy data and send it automatically. The energy monitoring devices is installed on different units for ventilation, water, heating and cooling pumps, district heating and electricity among others. The informations and data is communcated to the BMS and EMS. *"Monitoring and energy monitoring devices are used to optimize operation of the building"*, a respondent told us. To ensure as optimal energy efficiency as possible it is important to constantly monitor the building and to make adjustments to correct deviation in the building and the technical installations, according to a respondent.

The actual energy use has varied from year to year. *"There has been some good years and some bad years, but we expect the energy use to be bit lower because of the ammonia pump that has been installed"*, a respondent told us. A respondent feel that it will always be some sort of deviation (gap) between expected and actual energy use because it is not possible to calculate the activity and amount of users in the building correctly in advance, while at the same time, the weather and temperature varies for year to year. *"This is why we use the average of the actual energy use from the last three years to try and calculate the expected energy use"*, a respondent told us. There is also expected more users, since more people are taking an higher education. More users will most likely lead to a higher energy use according to a respondent. *"There has been several improvements the last years that have reduced the energy use, but this is generally in regard to improvement of technical installations and systems"*, a respondent told us. Generally the energy use has increased steadily, but there has been a turning point the last years where there energy use has reduced, according to a respondent.

"There could be many reasons for a gap between expected and actual energy use", a respondent told us. The building and the technical equipment is one factor that is mentioned; *"there is often chosen wrong solutions that do not fit well together"*. A respondent also mention the importance of continuous monitoring and correction. Optimal and efficient operation and maintenance of the building is also mentioned. The outdoor temperature is an important and unpredictable factor, according to the repondents. There is also the factor of increased activity and more users in Realfagbygget, especially more activity in laboratories, which use high amounts of energy. The main user or tenant at Realfagbygget is the faculty of natural sciences and technology. They have around 550 fume hoods, which has increased over the years. A respondent also think that there is too little focus and priority on energy use, especially among the users of Realfagbygget.

”Operation personell with good expertice and experience is an important factor, since errors often result in high and unnecessary energy use if not corrected”, a respondent told us. There is often a lack of people with necessary expertise and experience to start, operate and monitor a large building, according to the same respondent. Realfagbygget is also always available for the users, even at night, and it has not been facilitated for this activity, according to a respondent.

4.1.4.6 Evaluation

There is some disagreement in the respondents evaluation and description of the building. One respondent describe Realfagbygget as a great building, which is funcational in many ways, but that it is hard to operate. An other respondent describe the building as a partly good building to manange and operate, with the structural limitations and assumptions in regard to the building take into account. The building is described as a challenging building in regard to the way it is built; *”there is many challenges in regard to the technical solutions, which I see as expensive to repair and maintain”*. The building is also described as an interesting and modern building with a good overview.

All respondents feel that the management, operation and maintenance is well performed, even though there is a large potential for improvement, according to one respondent. There is a continuous development and improvement, which the respondents see as an imporant factor. *”The operation and maintenance plans are constantly improved, which ensures a good operation and preventive maintenance. The quality of our operations is important to us, the better operation, the less maintenance is needed”*, a respodent told us. They are happy with the use of Lydia, which makes it easier to keep track of the different tasks, cases and measures needed.

There are several challenges with the building. One is that Realfagbygget is open all day and night, which result in that there always is some form of activity and need for systems to run. *”There is possibly a big potential, but I think that a good and acceptable quality of the indoor climate takes priority over energy use”* a respondent told us, and continue by saying that; *”if you ask someone else, they might disagree”*. An increasingly visible challenge is that many installations and building components need to be changed, because the of the life time of those installations and components. Some are expected, while others unexpected. This leads to more errors and need for unexpected repairs, while at the same time it is too costly to upgrade and change everything at once. New installations require the need for new tuning and start up periodes, a respondent mentioned. *”Although we have managed to achieve a good operation of Realfagbygget, it is a challenge with replacements which means that we almost start over again”*, a respondent told us. To address the challenges, the respondents feel that it is important with good area planning and better zone and area management. It is imporant to work towards optimal operation, and follow-up on the operation and monitoring. A respondent also mentioned the importance of leadership and focus from the top, benchmarking and communication through the organization.

4.1.5 Interviews of users

In this section, the data and findings from the interviews of the users at Realfagbygget are presented. The section is structured based on the interview guide with the theory and literature chapter in mind. We start with the respondents (anonymously) to present their user profile, then go into their user behavior through building use, usage pattern, impact and influence of energy use, thoughts and focus in regard to energy use and saving, the gap between expected and actual energy use. Finally, we present their evaluation of the building. The citations is translated from norwegian to english by us with a focus to render as correctly as possible.

4.1.5.1 Respondents

We have interviewed four users of Realfagbygget. The interviews were conducted between the 6th and 22nd of April. Of the four respondents, there were one employee and three students. We will write about and mention the respondents based on their position - the employee and the students.

The employee is employed within the faculty of natural sciences and technology with responsibilities within HR and HSE. A general day varies based on meetings, conflicts and other matters that need to be managed. The employee has a master's degree in knowledge and innovation management. The employee started to work at the faculty of natural sciences and technology in 2001, and the faculty of natural sciences and technology has been located at Realfagbygget since it was ready for use in 2000. The employee is primarily located in an office in block D, first floor, which is an office only the employee use. The employee told us that; *"I have been located in the same corridor the whole period I have been here"*. There are around 400 people from the faculty of natural sciences and technology located in Realfagbygget, while they are around 1000 in total.

The three other respondents are students, which is their primary position at NTNU and in Realfagbygget. A general day varies based on subjects, lectures, exercise sessions, group-study and self-study. This is common for all three students, who generally use Realfagbygget more or less during a day, based on the agenda of the specific day. All three students is taking a degree on master's level, within different field of study - architecture and civil engineering (energy and environment and computer science). Two of the students have been users of Realfagbygget for almost five years, while one student has been a user for nearly six years. None of the students have a primary location, as in a fixed or permanent seating or place in the building. For this reason the primary location is based on a more flexible location aspect, which varies mostly between auditoriums, smaller teaching rooms, reading room, group rooms, the library, the canteen or the cafeteria. A student put it like this; *"localization varies clearly in relation to the year I'm at and what subjects and projects I have that* *year"*. This is common for all the students interviewed in regard to Realfagbygget. How many students that are in the classes of respondents have varied from year to year, and also varies according to the different subjects each student take. The subjects are more obligatory in the first years, while there are greater opportunities to select subjects freely and also select a specialization gradually towards the last year. The classes range from around 20 to 120 student, while the number of participants in various subjects range from about 15 and up to 150 and even more for some subjects. *"Some subjects have many participants, while other subjects have less demand and may be more specific so that there are fewer participants"*, a student told us. Subjects and lectures are held in different buildings across the campus, and it varies which subjects that are held at Realfagbygget. A student told us that; *"students and their representative classes often have a greater ownership feeling of the buildings that they use a lot and feel represented by"*. All the students interviewed in regard to Realfagbygget, feel that Realfagbygget generally is seen as a building they use for and in regard to their studies, but that it is not a building they mainly see as their main building, which is a factor that varies based on study area.

4.1.5.2 Building use

The employee (respondent) is mainly using block D, but is also using block E and B. More specific the employee use meeting rooms, offices, supportive rooms like printer rooms and corridors to get from point a to b. The emplyee also use block A, but only the canteen, which is located there. *"I mostly use the areas where we have activity, which is mostly our wings, that is block D"*, the employee told us and continue by telling that; *"I use block E and A less, and block B the least, where det library is"*. The use of the different areas varies and the employee find it difficult to specify in greater detail as this is not something the respondent is thinking about in the daily work life.

The students use Realfagbygget as one of several buildings during a regular day. Auditoriums and teaching rooms are mostly used in regard to lectures. Group rooms, the canteen and the cafeteria is used in regard to project or group work, or just when there is free time between lectures, to eat or other activies. The library and reading rooms are mostly used when the students study by them selves, or in small groups of two or three students. During the students years at Realfagbygget, there has been used various building area of different type and function. The students mainly use the different rooms in the first, second, third, and forth floor, and the first and second basement floor. In these floors the blocks used vary, but block A, B and C is the most common especially for the first and second floor, and the first and second basement floor. Block D and E is also mentioned. The building areas that are used the least is where faculties and institutes, among other, are located. Laboratories are also rarly used by the students who were interviewed in connection with Realfagbygget. *"I have been much in the first floor, and in the floor below the first floor, but not that much up fr-*

om the first floor. Often I tend to just go through the building", a student told us.

4.1.5.3 Usage pattern

For the employee, the use of the building is mostly based on a daily agenda, the degree of meeting intensity and tasks to be performed. The specific and permanent office is where the employee is mainly stationed and uses the building with the office as a hub in between usage of the other building areas. The usage pattern varies, but as a general standard, the employee enter the building from the first basement floor and take the elevator up to the first floor, and move towards the office where the employee is located. The light and the computer is turned on, and there is done adjustments in regard to temperature if necessary, either through opening a windows or through a radiator. *"Sometimes I only enter my office to place my coat and go to a meeting right away"*, the employee told us. In general, the employee has not a standard user pattern, but rather a user pattern which varies according to the agenda, tasks and meeting frequency of each day specifically. The fixed factors in regard to usage pattern is when the employee arrive at work, what building areas that are used the most, when the employee eat lunch and when the respondent goes home from work - to some degree.

The students arrive at campus with different means - one walk, one takes the bus and one use either a car or a bike. It is the main entrance or the entrance between the chemestry buildings which are mostly used. After the students have entered the building, they usually move to agreed locations, whether it is lectures in auditoriums or teaching rooms, or meetings in group rooms with other students. Sometimes they go to find a place alone to study, like a reading room or the library, which often is dependent on available seats. Mostly they go to specific locations that are agreed between students to meet up before an activity - this might be common areas, the canteen, the cafeteria or other rooms. The group move from there to a room or location based on what is on the schedule. This also include leaving the building to go to an other building at campus. *"I usually goes to Realfagbygget to take lectures, use group rooms or reading rooms, or to have lunch or dinner in the canteen, but this is not something I think about in daily life"*, a student told us. An other student said that; *"I would say that my user pattern varies from year to year. There are different reasons why I am at Realfagbygget. There has been used different rooms, there are different lectures, and there is always different things on the agenda. Some weeks the building is used often, while other weeks we are almost not there - so it has been quite variable"*. A student described the user pattern like this; *"I think we usually move and use the building as groups of different sizes - it is rare that I am at school without being with someone there. What we do vary of course"*.

4.1.5.4 Impact on energy use

The employee focus on the daily tasks and responsibilities and use the building, equipment and devices as needed. There is too bad sorting of garbage, too much printing and paper usage, and too much use of windows and radiators. *"I am one of many, I am a user of the building and have a job in the building, my presence will certantly affect the energy use, but how much I alone affect the energy use is difficult to say"*, the employee told us. The employee use different rooms, but think that it is easiest to look at the impact on energy use through the office where the employee is stationed. There the employee use a computer, which is on during the work day. The light is also on during the work day and is turned of when the employee goes home. The lights go off automatically at night. The employee may affect the indoor climate through the use of a window and a radiator. *"If it is hot I open the windows, it is it cold I turn on the radiator - I am not aware or thinking about how that affect the energy use during a work day"*, the employee told us. The employee is more aware about the energy use at home, mostly because at home it is the employee who is responsible and is the one to pay the energy bill.

The students interviewed is not very reflected on what they do to affect or impact the energy use at Realfagbygget. One student think that it is limited and varying what one student do to influence the energy use. A student put it like this; *"No, I do not have many thoughts about that. This is not something I think about at all in fact. I am more aware of what is happening in relation to me, than in terms of what I do and how I affect the energy use. One example is that paper has been replaced with fans to dry hands on the toilet - something I find annoying"*. A common thought for the students is that they are in the building to study and learn and not to think about how they affect or impact on the energy use in their everyday lives. A student think that they have an impact on the energy use through being in the building and by using different rooms and support functions for their needs as students, for example, to turn on or off the light. The students have generally no specific suggestions as to how they can control the indoor climate. The students is more concerned about the energy use at home, where they have to pay, atleast a part of it. *"When I walk out of a room at home, I am more concerned about turning off the light or heat, or to close the windows because it goes out of my pocket. I am not thinking like that at school"*, a student told us. An other put it like this; *"I am probably more aware of the energy use at home, when I have to play for it. I find it hard to say what I, one of thousands of users can accomplish in terms of energy use. At home we are just two people, which makes it much easier to have a good focus on managing the energy use"*.

4.1.5.5 Energy use and saving

The employee think that it is been little focus and that it still is little focus on energy use and saving. There has been a greater focus lately, after it was created an energy efficiency project that a fellow employee is participating in, but it is not a big visible focus beyong that, no competition or pressure towards energy saving. The employee describe that there is a bad link between the management, operation and the users. *"I think there* *is a need for a more public disclosure of energy use and costs, and it is also important to know a little more about the operation and what the user can do", the employee told us.* The employee think that if the users do not see the impact of what they do, then how and why should the users change their behavior. *"We are not motivated and do not know directly what we are doing right and what we are doing wrong"*, the employee told us. There is also mentioned that the various parties in the building is doing their thing and that there is poor communcation between each of them. Visibility, communication and follow-up is the three main measures being mentioned by the employee.

The students do not feel any focus on energy use or saving. They feel that it is generally little focus on this matter and believe that this translate to most of the users of the building. *"There is no visibility - this could probably be because the students are at the building to study and not to have a major focus on energy usage. There is a greater focus to ensure that we feel good, that we are satisfied and that we are happy with our place of study"*, a student told us. To point attention to energy saving there is mentioned a combination of factores from the students. One student told us; *"I think it is a combination of visibility in regard to what we can do and a facilitation towards us so that we can reduce our impact"*. Communication is an other factor with examples to put up posters or sheets which provides information and tips for energy use and saving. *"It is certainly several everyday things that we can do, but that is not focused on as a student. It is easier to remember such things at home, so I think it is important to be reminded of thing we can do at school", a student told us.* One student suggest campaigns to highlight various measures and what the different measures contributes with. Other measures to to affect and reduce energy use is to install more sensors and automation in the building. *"People want to save the environment, but in a hectic life, this is not a priority. I think this is the same for energy use and saving, people forget it through the noise of other priorities"*, a student told us and also reflect on that the building is so large with so many users that need to change their behavior and focus to affect energy use and saving.

4.1.5.6 Gap

After understanding the meaning of gap, the employee think that it is a combination of different factors that result in a gap between expected and actual energy use. From a HSE perspective the employee know that Realfagbygget has alot of old fume hoods which is not energy saving all. The old fume hoods are installed in relation to different laboratories. The employee think that there must be several factors like the fume hoods that could be improved through different measures, and that the use in relation to computers and lights play a small part in regard to the installations that support the building and the users. The number of users and the operation is also mentioned to play a part in regard to the gap. *"We do not know if there is a gap or whether the gap is good or bad"*, the employee told us.

The students see the gap between the expected and actual energy use as a combination of the building and the users using it. The building is described as big and diverse, with many different users. One student point to the extensive use of glass, and other refer to the location of the building and the varied weather. Another student reflected about the calculation, location, the communcation and the visibility; *”it has probably something to do with how it is calculated, the location of the building, lack of communcation and visibility of what we as users can do”*. There is also talk about the user pattern, which is one of the questions we asked in the interview, but that it mainly is the building that is the factor for the gap; *”this is a building with many different users with different patterns as you called it, that may have some impact, but I think the building itself is the main factor in regard to this gap, and that my contribution do not have much to do with it”*.

4.1.5.7 Evaluation of the building

The employee feel that the building is generally a good building. The offices could be better, and is described as too long and narrow which makes it hard to break them up so that more than one user may use it at a time. The indoor climate is perceived as poor inside the meeting rooms, and sometimes inside the office. Other than that the employee feel that the needs and expectations are meet good enough. An improvement mentioned is the that some laboratories is located within the office areas and corridors. They should be moved from the employees HSE perspective. There has been implemented some improvements to make the users happier, such as inserting windows that may be opened. *”We have learned to live with the building as it is, have adapted to it, and generally speaking we have it very good here”*, the employee told us.

The students describe Realfagbygget as a very convenient building, open with good lighting and a nice modern look. The building is percieved as maintained and tidy, with plenty of space and fine details inside the building. The building is also described as easy to orientate oneself in, even though it is large. The quality of the various rooms is defined as high. One student feel that it may be a little hot towards the summer, and a little cold in the winter, especially in some auditoriums and reading rooms. One student feel that not all the reading rooms works as they should and that some auditoriums becomes very dense and have bad air after a while. The needs and expectations are generally mentioned as good, with a few exceptions presented above. *”Since I am at the building to think and study, I find the indoor air quality and temperature important. I feel that the quality varies in some rooms”*, a student told us. Improvement areas mentioned are in relation to the factors above, slightly better balance in the indoor climate in some auditoriums, reading rooms and group rooms. One student also feel that there should be more smaller group rooms, since they often are occupied, and that it feels inefficient to go around in the building to look for rooms if you have not booked a room in advance.

4.2 Case - Miljøbygget

4.2.1 Benefits and risks

Compared to Realfagbygget, Miljøbygget do not have the same amount of benefits and risks associated with the selection as a case in our case study. Miljøbygget is a relatively new building, over four years old, which means that it is built according to newer and stricter regulations (TEK 07) and standards, especially considering that it is built as a low-energy building. At the same time, the building has not been operated for a long periode of time, and may still be characterized by a break-in periode in this regard. It was to some degree harder to find willing respondents and harder to find the time for the interviews to be conducted. The result was fewer respondents compared to Realfagbygget. This may be considered as a risk. There are more detailed documentation available about Miljøbygget, which we consider a benefit. The energy use is reported weekly to Entro, which made it easier to get hold of and manage the data. We have received energy figures back to 2011, and have also the estimates of the expected energy use from the design phase. The management, operation personell and most of the users have been with the building since it was constructed and ready for use. All in all, some benefits and some risks, but not at the same level as for Realfagbygget as a selected case.

4.2.2 Presentation

4.2.2.1 General description

Miljøbygget, also refered to as KLP-bygget, is described as; ”Norway’s most energy efficient office building upon completion” (our translation) (Veidekke 2014). The building was completed in november 2009 and is one of Enova’s reference buildings (the project was supported with funding from Enova). KLP Eiendom (the construction client) wanted a flexible and moderne office building which had a major focus on energy efficiency (Norske arkitekters landsforbund 2013). As a result the building project was developed with a central focus on energy solutions from the design phase and until the completion - a continuous focus on energy from all parties (Norske arkitekters landsforbund 2013, Veidekke 2009, Veidekke 2014). There has also been a focus on low environmental impact through the construction phase (Norske arkitekters landsforbund 2013).

Miljøbygget is a medium-sized office building with a total of six floors. The building consists of 16 400 m^2 (GFA) and approximately 13 100 m^2 rental area and 3 300 m^2 UFA of technical rooms, storage and underground parking (Veidekke 2014). The building area mainly consists of rental area with associated common areas (Norske arkitekters landsforbund 2013). There is mainly open landscape offices and cellular offices. There are also associated meeting rooms of different sizes. The common areas (located on the first floor) is a semi-climatised atrium, meeting rooms, a canteen and a partial red sphere shaped auditorium for 54 persons (Veidekke 2014).

There has been a focus on flexibility in regard to the utilization of the premises with high ceilings, environmentally correct materials and lots of air and light. This is reflected in the rental areas with three different widths of the office wings to open up for the needs of the individual tenant (Norske arkitekters landsforbund 2013). Miljøbygget has a eastern and western block that are connected with bridges on the different floors through a glass atrium - a main common area (Veidekke 2014). The main common area inside Miljøbygget consists of a green and glass roofed square area (the atrium), which rises to the south and is characterized by three terraced waterfalls with communcation bridges and hanging gardens. The atrium function as a open-access common area with the with the impression of a lush and green lounge. The red sqhere is constructed partly inside and partly outside, identify the building and marks the main entrance, which opens out into Elgeseter (a street in Trondheim) through a glass facade. The technical rooms is located in the basement and on the roof (Norske arkitekters landsforbund 2013). The atrium is shown in picture 5 below with the bridges and the rising to the south. The red sqhere is shown in picture 6 on the next page. The atrium with the canteen in the background is shown in picture 7 on the next page.

Picture 5 - The atrium with the bridges (Photo: Daniel R. Hansen).

Picture 6 - The red sqhere from the inside (Photo: Daniel R. Hansen).

Picture 7 - The atrium with the canteen in the background (Photo: Daniel R. Hansen).

4.2.2.2 Address

The address of Miljøbygget is Professor Brochs gate 2, 7030 Trondheim.

4.2.2.3 Localization

Miljøbygget is correctly located in Norway, Sør-Trøndelag, Trondheim, Dalsenget/Elgester, Professor Brochs gate 2, 7030 Trondheim. Figure 21, 22 below and 23 in the next column shows the location and orientation - north is up.

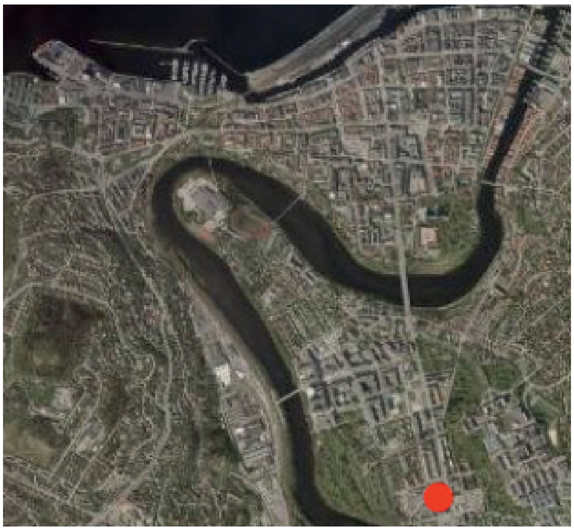


Figure 21 - Trondheim (FINN kart 2014).

Figure 22 - Dalsenget/Elgester (FINN kart 2014).

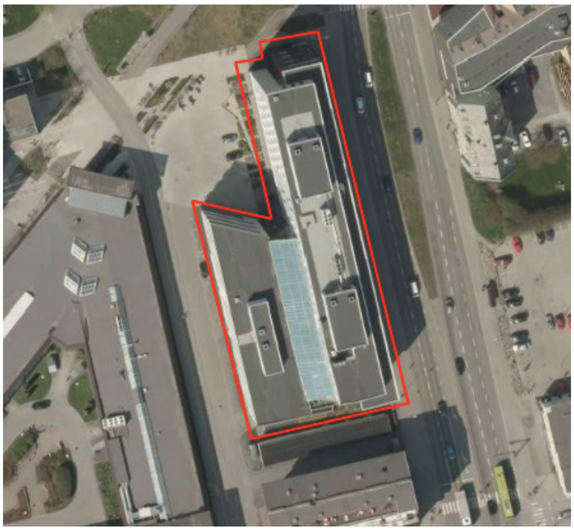


Figure 23 - Miljøbygget (FINN kart 2014).

4.2.2.4 Floor plans

Figure 24 on the next page show the floor plan for the first floor at Miljøbygget - with different colors and names for the different building blocks which is commonly used at Miljøbygget in regard to the description and according the respondents. The atrium is in between and partly inside the eastern block. We have added additional floor plans for Realfagbygget in the appendix. The floor plans support the descriptions about the building aswell as the interviews to get a better overview and understanding of the case study.

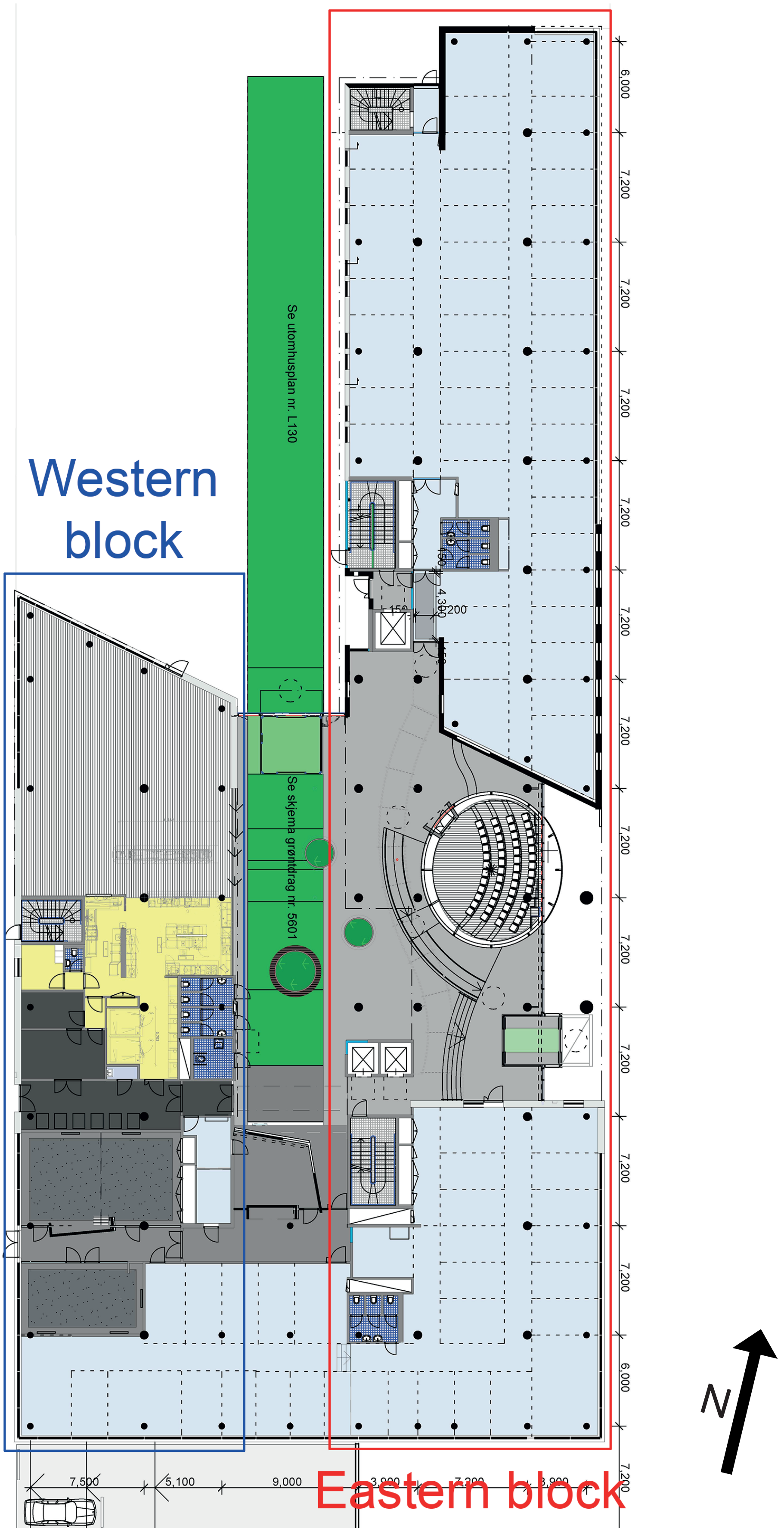


Figure 24 - Edited floor plan of the first floor at Miljøbygget (Norske arkitekters landsforbund 2013).

4.2.2.5 Project costs

Total project costs was approximately 235 000 000 NOK (Norske arkitekters landsforbund 2013) which gives 14 329 NOK per m^2 GFA.

4.2.2.6 Building technical

Miljøbygget has three different net widths of 13, 16 and 17 meters. The building structure has U-values according to TEK 07 (Veidekke 2014) and consists mainly of a place molded concrete constrcution, which is treated and require little maintenance (Norske arkitekters landsforbund 2013). Miljøbygget is oriented with the main facades facing east and west, where there is high windows to optimize daylight conditions. The facade solutions has been established to achieve low infiltration and thermal bridge values to keep the extent to a minimum. There is an active use of glass in the atrium aswell as thermal mass. An area efficient floor plan with semi-climatised atrium work as the communication hub. The building has few elevators and stairs. Lighting, daylight, ventilation, heating and cooling is demand controlled. There is also sequence control of heating and cooling, while the offices regulates ventilation and lighting with presence sensors. There is CO^2 sensors installed in the auditorium to controll the ventilation there. Miljøbygget has a balanced ventilation with heat recovery of 80 percent efficiency. Exterior sun shading devices is automatic and installed on all facades facing the sun (Norske arkitekters landsforbund 2013).

To achieve an energy efficient building there has been installed, constructed and established use of heat recovery through heat pumps, natural ventilation, super-insulating glass, demand controll of heat, ventilation and low energy lighting with daylight control. The concrete surfaces has free cooling and there is utilization of the condenser heat from servers and computers. There is exposure of concrete in the ceilings. To continuously measure and control the building optimally, there is initiated a comprehensive monitoring program with 60 energy monitoring devices (Veidekke 2014). There has been implemented passive house measures to reduce heating and cooling demands. District heating is established with a waterborne heat through radiators and ventilation units. The heat pumps (air to water) work as a cooling unit during the summer. The thermal mass of concrete surfaces and floors open for a utilization of passive solar energy, while the need for cooling is reduced. The heavy constructions of the building are exposed to achieve best possible thermal inertia. There is also facilitated for a low energy loss in the entrance zones of the building. There has been separate control procedures to ensure the quality of the building. Miljøbygget has outdoor and indoor bike parking (Norske arkitekters landsforbund 2013).

Based on testing (full-scale leakage testing of facades) and estimations, Miljøbygget should be able to have a net energy demand of 110 kWh/m^2/year and a delivered energy demand of 83 kWh/m^2/year - about half of the requirements in TEK 07 (Veidekke 2009, Veidekke 2014). Total net energy use is estimated to 114 kWh/m^2/year based on ventilation and heating of rooms (8,6 kWh/m^2/year), domestic hot water heating (5,0 kWh/m^2/year), cooling (8,2 kWh/m^2/year) thermal batteries (11,9 kWh/m^2/year), lighting (25,1 kWh/m^2/year), pumps and fans (20,7 kWh/m^2/year) and technical equipment (34,5 kWh/m^2/year). Annual energy needs purchased are estimated to 94 kWh/m^2/year (Norske arkitekters landsforbund 2013). Miljøbygget has a BMS and EMS among other systems to control and monitor the building, according to a respondent.

4.2.2.7 User technical

Miljøbygget has different users in different organizations, who are tenants of the building. Each organization has its own rented area. The users have different needs in regard to what their organization do and their position in the organization. Generally each user or employee has an office space with equipment such a computer. Various chairs, tables and other furniture is placed in the different rooms of the building for the different users, tenants and the function of the rooms. Power outlets is available in most rooms to support the use of a laptop or other devices. There is mostly an office landscape where the lighting and climate is automated with a slight possibility to affect the indoor climate through a control device placed on the wall. This is mostly the same for the meeting rooms. It is not possible to open the windows. There is elevators and stairs in the building. There are common areas open for the users, a canteen, an auditorium, wardrobes, meeting rooms and parking in the basement. All this is based on the respondents.

There has been established information and training for the users of the building to support and achieve the aim of energy use (Norske arkitekters landsforbund 2013).

4.2.2.8 Owner

Miljøbygget is owned by KLP Eiendom, which also acted as the construction client of the project, according to a respondent. KLP Eiendom is one of the largest facilities managers in Norway (KLP Eiendom 2014a).

4.2.2.9 FM organization

KLP Eiendom is the FM organization that manage and operate the building, according to a respondent. The buildings in Trondheim is managed by a subsidiary called KLP Eiendom Trondheim (KLP Eiendom 2014b).

4.2.2.10 Users

As described before, Miljøbygget has many different users. The tenants is the organizations who rent area in Miljøbygget. These organizations has employees, which is users of the building. The tenants (organizations) of the building is Enova SF, Sweco Norge AS, Sedicon AS, IBM AS, Bitreactive, DEFA AS, Metier, Norsk Helsenett SF, DNV GL, CopyCat, Kompan Norge AS, Helsedirektoratet and Phonero. KLP Eiendom has employees working at the building to ensure operation and maintenance, these may also be described as users. The same goes for the canteen personell. There are also external service providers who come to the building for repairs on technical installations among others. The end user at Miljøbygget are mainly the organizations and their employees. All this is based on the respondents. We do not have the exact numbers of users, this vary in regard to how much area that is rented out, and how big the tenants (organizations) are, according to the respondents.

4.2.3 Energy use, gap and label

4.2.3.1 Expected energy use

The expected and estimated energy use from the design phase was presented in section 4.2.2.6. Through our interviews, we found out that expected energy use for Miljøbygget for each year is calculated based on the energy use for the last year with the use of temperature correction. We will use the same calculation method. Findings from the interviews are presented later in this chapter. We have acquired energy figures back to 2011, and will calculate the expected energy use from 2011 to 2014. Table 8 below show expected energy use for each year. In figure 25 below is a graph showing the development in the expected energy use from 2011 to 2013. The numbers used are based on the total energy use figures provided by Entro. The expected energy use in 2011 is be based on the delivered energy demand of 83 kWh/m^2/year.

Year	2011	2012	2013	2014
Expected energy use [kWh]	1 361 200	1 591 000	1 866 000	1 654 000

Table 8 - Expected energy use for Miljøbygget.

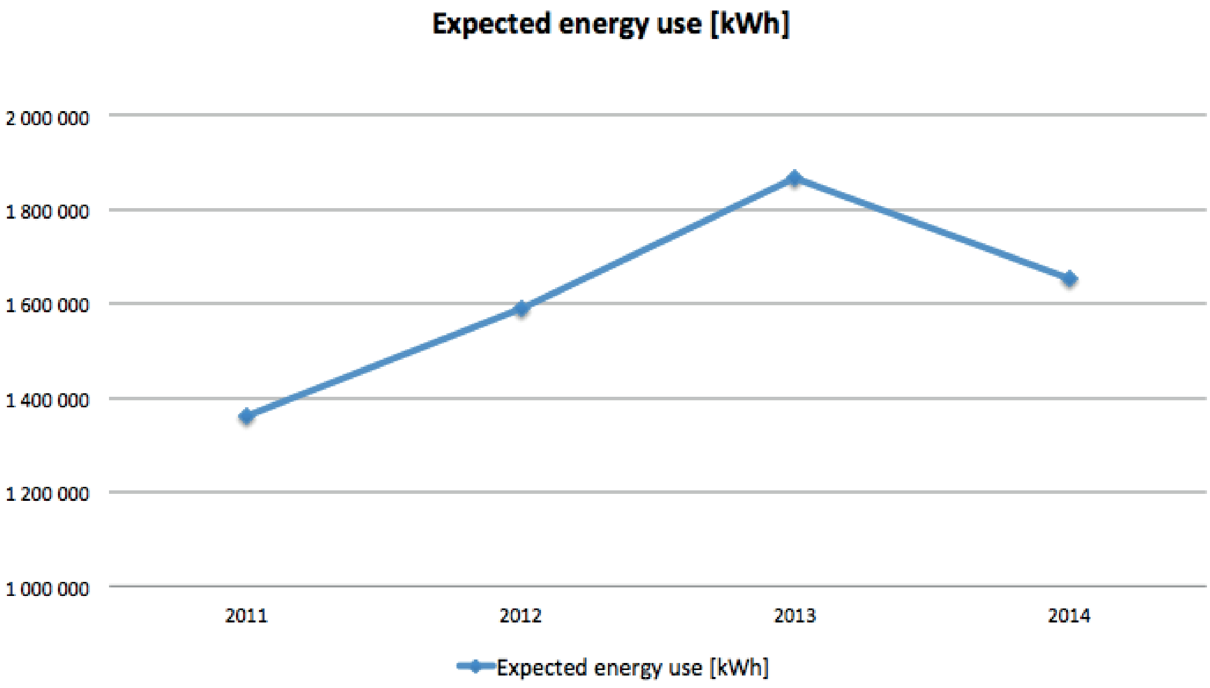


Figure 25 - Expected energy use for Miljøbygget.

4.2.3.2 Actual energy use

The actual energy use at Miljøbygget is data measured with energy monitoring devices attached to the technical installations and gathered with a EMS through the BMS and reported to Entro, according to a respondent. Table 9 below show the actual energy use for each month and year. Table 10 show the proportion of electricity use for Miljøbygget. Figure 26 below show a graph for each year and the energy use per month. In figure 27 on the next page is a graph showing the development in the actual energy use from 2011 to 2013. The numbers used are based on total energy use figures provided by Entro.

Month	2011	2012	2013
January [kWh]	194 000	220 000	209 000
February [kWh]	157 000	190 000	181 000
March [kWh]	150 000	170 000	177 000
April [kWh]	101 000	135 000	134 000
May [kWh]	105 000	124 000	120 000
June [kWh]	99 000	119 000	119 000
July [kWh]	96 000	115 000	104 000
August [kWh]	102 000	129 000	126 000
September [kWh]	120 000	129 000	128 000
October [kWh]	134 000	155 000	101 000
November [kWh]	151 000	175 000	126 000
December[kWh]	182 000	205 000	129 000
Actual energy use [kWh]	1 591 000	1 866 000	1 654 000

Table 9 - Actual energy use for Miljøbygget.

Year	2011 [%]	2012 [%]	2013 [%]
Proportion of electricity	73,24	74,21	74,08

Table 10 - Proportion of electricity use for Miljøbygget.

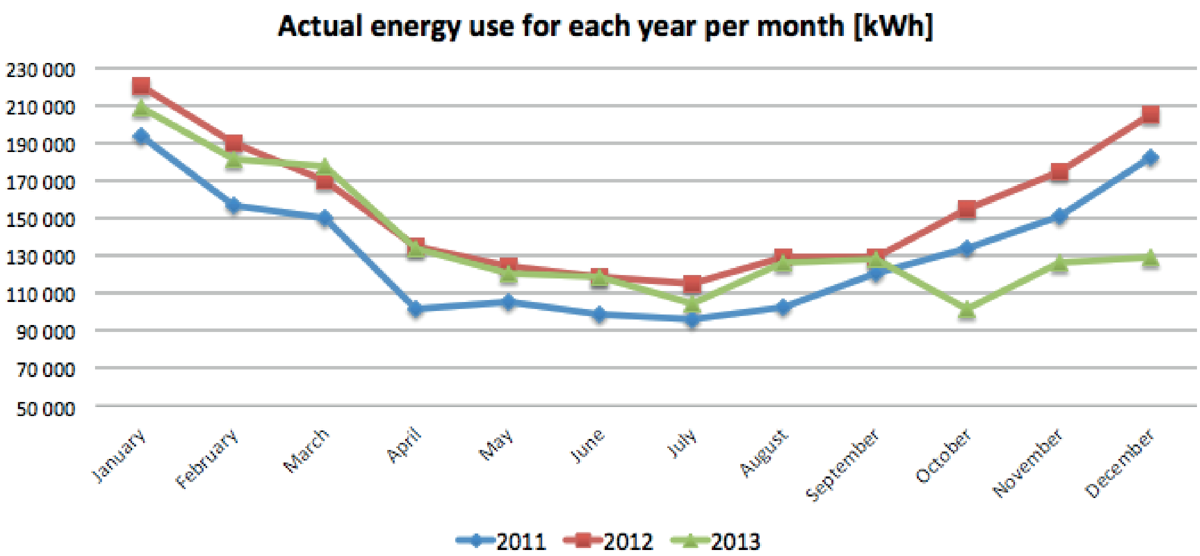


Figure 26 - Actual energy use for Miljøbygget per month.

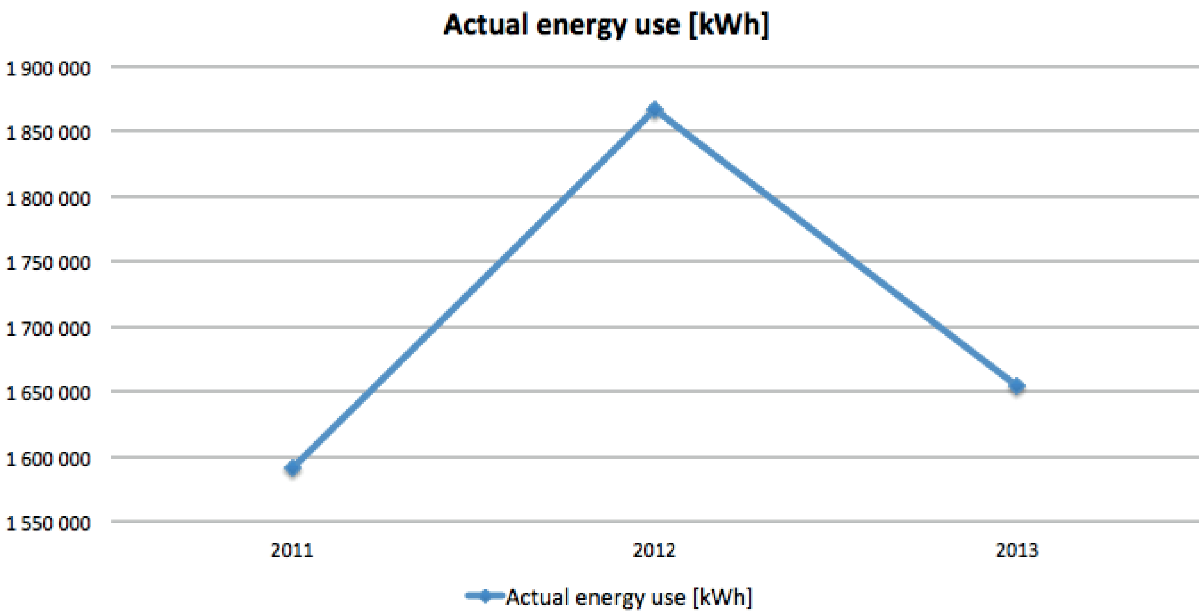


Figure 27 - Actual energy use for Miljøbygget.

4.2.3.3 Gap

By comparing the calculations for expected and actual energy use it is possible to calculate the gap. Table 11 below show the gap between expected and actual energy use. Figure 28 below show graphs for the expected and actual energy use - illustrating the gap.

Year	2011	2012	2013	2014
Expected energy use [kWh]	1 361 200	1 591 000	1 866 000	1 654 000
Actual energy use [kWh]	1 591 000	1 866 000	1 654 000	
Gap [kWh]	-229800	-275000	212000	

Table 11 - Gap between expected and actual energy use for Miljøbygget.

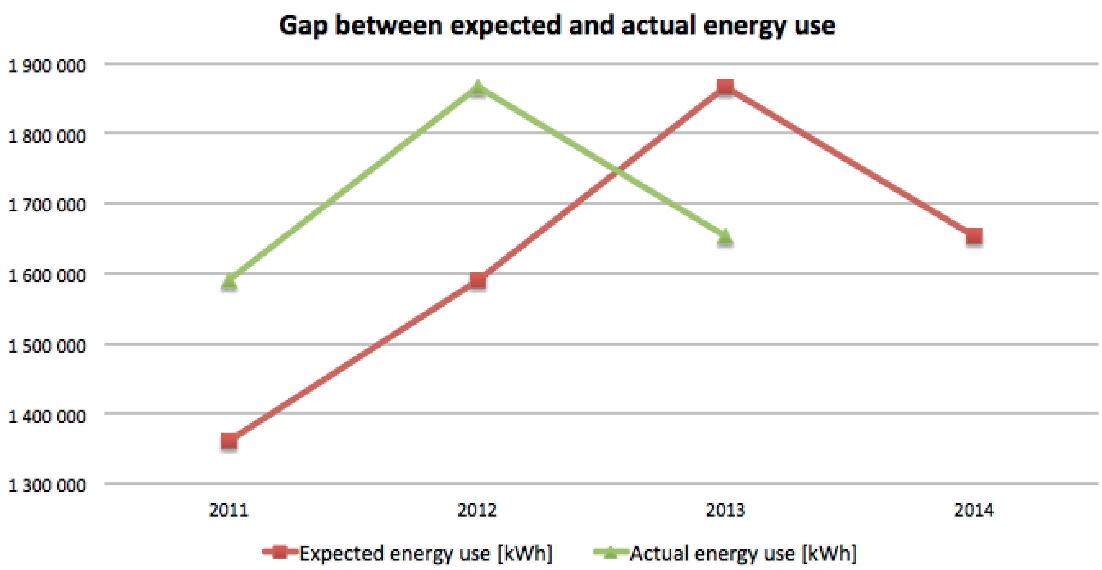


Table 28 - Expected and actual energy use for Miljøbygget.

4.2.3.4 Energy label

Miljøbygget has gotten energy label B with a light green color, according to a respondent.

4.2.4 Interviews of facilities managers

In this section, the data and findings from the interviews of the facilities managers at Miljøbygget are presented. The section is structured based on the interview guide with the theory and literature chapter in mind. We start with the respondents (anonymously) to present their management profile, then go into the organization, management and tasks, calculation and measurement of energy use. Finally, we present their evaluation of the building. The citations is translated from norwegian to english by us with a focus to render as correctly as possible.

4.2.4.1 Respondents

We have interviewed two facilities managers of Miljøbygget. The interviews were conducted between the 24th of April and 2nd of May. Of the two respondents, one is a property manager and one is a operating technician.

The property manager is an employee of KLP Eiendom and is not stationed at Miljøbygget. A general day varies between marketing, rent management, tenant contracts and negotiations - with administrative tasks and meeting in regard to this. The property manager has a bachelor's degree in economics and administration. The propery manager has been a facilities manager of Miljøbygget since it was completed in 2009, while being a part of the process of planning and decision since 2007 in regard to the building. The respondent has had the position of property manager since 2001 and have been working in the business area of facilities management since 1994.

The operating technician is an employee of KLP Eiendom and is stationed at Miljøbygget. A general day varies between different tasks to operate and maintain the building with smaller tasks such as changing lamps included. The operating technician is a certified tinsmith, but have had the current position and been a operator of the building since it opened in 2009. Before this, the respondent worked as a certified tinsmith.

4.2.4.2 Organization

KLP Eiendom is the organization that manage and operate Miljøbygget - split between a technical department and a management department. The technical department has the main responsibility to manage and operate, while the management department has the responsiblity in regard to the tenants, contracts and negotiations. A respondent said it like this; *"the management department 'own' the tenants, while the technical department 'own' the building"*. The organizational structure has a management on top, which includes a daily manager, a property manager, a technical manager, a finance manager and a project manager. There are four departments below the management, a management department (four employees), a finance department (three employees), a technical department (eight employees) and a project department (two employees). It is the operating technician who has the main responsiblity for the daily operation of Miljøbygget, while the management department has the responsibilities in regard to tenant management and contracts as stated before. The finance department is responsible for the economical aspects, while the project department has the responsibility of buildings, rebuilding and other project tasks. There is also a degree of outsourcing of services.

4.2.4.3 Management and tasks

The responsibilities and tasks are different between the two respondents interviewed. The operating technician is stationed at the building, while the property manager is stationed at KLP Eiendom's premises. For the respondent stationed at the building, the task is mainly to ensure daily operations with additional maintaining and supporting tasks. The respondent told us that; *"my tasks can generally be seen as predictable and unpredictable tasks"*. The predictable tasks is mainly to ensure the operation of the building through BMS, control and monitoring systems, and tasks which is planned before hand. The unpredictable tasks is not planned, but rather tasks that are detected by monitoring the building or conditions that are reported. The unpredictable tasks could be leakage, temperature deviations, the need for garbage disposal, changing fluorescent tubes. The users of the building can contact the respondent stationed at the building through mail or phone. For this reasons the respondent told us that; *"My work day varies greatly, espesially in relation to the unpredictable tasks"*.

The respondent stationed at KLP Eiendom's premises, the responsibilties and tasks is all about customer and tenant responsibilities, contrating and marketing. More specific to define and write offers, negotiate contracts, have customer contact and support, find solutions, suggest measures and improvements and participate in project developments.

Their vision is; *"The best partner for the time to come"* a respondent told us. To ensure their vision, it has been set a series of goals. They shall keep updated management plans and have a balanced goal management in regard to clean, clear, safe and secure facilities. To do this, it is important that each employee has their own custom action plan each year. They want an average occupancy rate of minimu 97 percent and an actual customer satisfaction rate of 68 percent. They perform client (tenant) surveys every second year, and have annual customer visits during each year. I was clear that the property manager had a much better overview of the organization and objectives.

The building is managed and operated in accordance to KLP Eiendoms routines, which is defined in their quality system based on ISO 9001 and ISO 1401. The respondents feel that the building is managed and operated as intended. Energy use is a factor that is a bit higher than expected in regard to the calculations and estimations for the building. A respondent told us that; *"it seems li-*

ke it's rare that energy calculations done before the building is finished, corresponds to the actual energy use". The respondents feel that Miljøbygget is managed and operated proffessional with a focus on a continuous monitoring and follow-up on waste separation, energy use and saving. They have a good follow-up on the building's tenants and try their best to ensure a good environment for all the buildings users. *"We try to make it as optimal as possible based on the assumptions that we have"*, a respondent told us. The building is demand controlled and works like this; when a user enter an office area, there is a light sensor than detects activity, and the light is turned on, this sensor communicate with the ventilation, and the ventilation is turned on which increase the airflow, then the temperature is measured and if it is too cold, radiators is turned on if needed. The tenant mix is also an important and dependent factor in regard to the building. The tenant mix, the composition of the different tenants, may vary during the year, which impact how they manage and operate the building, especially in regard to energy use and saving. The tenant mix is monitored to ensure optimal operation. *"We have daily monitoring of the building which ensures that we can keep track, but to optimize the building, we have to educate the tenants to the best of our ability"*, a respondent told us.

4.2.4.4 Calculation of energy use

To calculate the expected energy use there is not developed any energy use budgets for management and use, but the facilities management of Miljøbygget use historical figures, the energy use from the last year, as an indication of the expected energy use. *"We use the last years energy use as indications for expected energy use, we may need to make some adjustments if there is a major tenant who will move in or out during that year, but mostly we use the last years figures and have nothing else to relate to"*, a respondent told us. Temperature correction is performed. The respondents is very clear on that calculations based on standardized figures is not realistic, and stesses that it is imporant to use real indications for the expected energy use since this is related to costs, which is important to the customers (tenants). The deviation between expected energy use and actual energy use may surprise the tenants if it is much more then estimated. *"We have to relate to, or try to hit the actual energy use as close as possible, to do this, we must use the real numbers for the building, we have no other options"*, a respondent told us. The respondents also told us that they try set energy goals in regard to reduced energy use, but this is not a part of the expected energy use calculations. It is the technical department who carry out the calculations for expected energy for each year. There was calculations for expected energy use performed in the design phase, with a follow up when the building was constructed and measured.

4.2.4.5 Measurement of energy use

To monitor and measure the energy use at Miljøbygget, there is installed between 60 and 80 energy monitoring devices in the building. The informations and data is communcated to BMS and EMS and reported to the electric power plant and to Entro. Each monday they go over the last weeks monitoring results, while the results are collected on an hourly basis. *"We have measures and monitoring for each ventilation system, each light board in each floor and for the heat pumps and so on - everything is measured"*, a respondent told us. A respondent said that they are always ready to tune the technical installations and devices, if there is a leakage or some type variations. *"We try to find and fix a problem as quickly as possible, if we see variations"*, a respondent told us. To achieve this, they are very dependent on good monitoring and control systems in the building such as a BMS, EOS and a shading device system. Both the respondens feel that it is a paradox in regard to having a optimal and energy efficient building. They work hard to ensure that the building is optimal, while not getting so much back, except for satisfied tenants. *"It is the tenants who benefit from us working hard to save energy, but atleast it gives us an edge in the market"*, a respondent told us. The respondents express that it is a preference to be in an energy efficient and optimized building, but that it is constructed more and more low-energy building now that before.

The actual energy use has been higher than what was expected before the building was contructed, and there has been a balance between a positive and negative development from what is expected. The respondents think that the development should be getting more positiv in the years to come. There is a gap between expected and actual energy use, and the respondents feel that it is hard to get it to correspond. There are several reasons for this, they spend more time than expected to fill the building with tenants in the beginning, and since the building is demand controlled, they had to heat areas that where not rented out because some users experienced a indoor climate they where not satisfied with. This is because the ventilation system in the building run across the facades and not on each floors. Since the building is based on automated demand controll the system register that there is not people in an area and set minimum values for the indoor climate in that area, which at some point effect the temperature in other areas. It takes time to find the optimal tuning and operation of the building, which is an important factor for Miljøbygget in regard to the respondents. The tenants and the tenant mix is also an important factor for the energy use - since each user are different and to some degree have different equipment needed for their jobs. Some users have one computer, while other may have several, and up to six computer screens. The respondents say that they encourage people to save, but the users need energy to carry out their tasks and jobs. They communicate the energy statistics for the building, so that the users may see the results and their effect and impact on the energy use. The outdoor temperature is also an important factor, both in regard to how much heating or cooling that is needed, but also in regard to the expectations and needs of each users. Even though the building is robust with building measures to ensure a low energy use, need for heating and cooling, some users expect a certain indoor climate, even though it is really cold outside, and they do not dress accordingly, which they might do at home, a respondent suggests. *"Yes, well, when it's minus 20 degrees outside, and some people go to work lightly dressed, but you are not lighty dressed at home in these conditions. At work you demand more and we can not heat to 24 or 25 degrees for people to go lightly dressed during winter"*, a respondent told us. This result to complains in some cases, which is best handled to follow-up and hear the one filing the complaint out, according to a respondent.

4.2.4.6 Evaluation

The respondents feel that Miljøbygget is a smart and responsive building, which has been easier to manage and operate over time. It takes time to tune the technical installations and devices, while at the at same time have to deal with different users and a varying tenant mix. The support from the monitoring devices and system makes it easier to have a control over the building. The respondents feel that they do a good job as facilities managers for Miljøbygget, experiences help them to performe better, both in regard to the building and their users. The feedback from the respondent suggests that they are generally satisfied with KLP Eiendom as a facilities manager. A respondent think that the ventilation should be based per floor and not across the floors as it is now, to adapt to different tenants and users. Now they have to find a balance between the users of the building.

There has been some challenges in regard to minor leakage of water from the roof. A major challenge in regard to a demand controlled building is component failure, which impact the whole building. Miljøbygget had a component failure in the damper actuators, while the building was in operation. This failure was not showed on their monitoring systems, but was found after several complaints in regard to the ventilation. This happened between 2010 and 2011, and resulted in air of different temperature moving randomly in the building. To fix this the supplier had to remove 600 damper actuators, while the building was in use. The users was generally so tired of the unbalanced indoor environment that they took the reparing periode okay, although it was a lot of disturbing noise at times.

To ensure energy efficiency through management and use the respondents feel that it is important to work towards an optimal tuning of the building, monitoring the building and reviewing energy usage to identify areas for improvement, both related to the management, operation and possibly the users. The respondents stress that it is not always easy to influence the users, since they are paying customers. The repondents tell us that they have a cooperation with Entro, which they report their energy use to. There are constant efforts to monitor and save energy - which is an imporant aspect of this building. *"We are looking for opportunities to do things differently to save energy all the time"*, a respondent told us. An example presented is to shut down the heating and cooling pump on the roof, since there is a periode now that they neither require supplemental heating or cooling in regard to the outdoor temperature, untill there is a need for cooling. This is possible because of the heat recovery units in the building. *"This may save us a lot of money, because of the large systems that are costly to have active and operate"*, a respondent told us.

4.2.5 Interviews of users

In this section, the data and findings from the interviews of the users at Miljøbygget are presented. The section is structured based on the interview guide with the theory and literature chapter in mind. We start with the respondents (anonymously) to present their user profile, then go into their user behavior through building use, usage pattern, impact and influence of energy use, thoughts and focus in regard to energy use and saving, the gap between expected and actual energy use. Finally, we present their evaluation of the building. The citations is translated from norwegian to english by us with a focus to render as correctly as possible.

4.2.5.1 Respondents

We have interviewed three users of Miljøbygget. The interviews were conducted on the 2nd of May. All the three respondents is employees.

The respondents are emloyees at Enova, one employee is a senior advisor, while the two others are associates. Their main tasks is to work with applications and application processing in regard to energy efficiency of buildings. One respondent is often out of the office to be in dialogue with parties in the construction and real estate industry and also to initiate projects. The employees is educated within engineering on a bachelor's or master's level, while the senior advisor also have a economic degree. Enova has been a tentant at Miljøbygget since it was opened in 2009, and is primarily located on the third floor in the eastern block. They have an open landscape office solution with a primary location. Enova has around 65 employees in the building.

4.2.5.2 Building use

The respondents use the rented area on the third floor in the eastern block. They use their primary office location in the open landscape, different meeting rooms, the canteen and the parking in the basement. The common areas such are the corridors or the atrium is used as a communcation area when moving in the building. It is mainly the rented office area that is used, primarily their location at a desk, but also meeting rooms. The canteen is the least used area, which they only visit once a day, or some times they eat else where.

4.2.5.3 Usage pattern

The usage of the building varies a little for each respondent based on their agenda. They are primarily in the office landscape, while one respondent has a higher meeting intensity then the others. Two of the respondents are generally at the building five times a week, while one respondent is at the building four times a week as an average. They enter the building either through the basement parking or through the main or back entrance. From there they take the elevator up to the third floor, or in some cases use the stairs. From there they enter a reception area, find their primary office location and go to a meeting if that is on the agenda. *"The usage pattern is that I am mostly in the office areas, but I also use the canteen, but typically only once a week because we have a lunch arrangement on wednesdays, otherwise I am up here, or out"*, a respondent told us. The respondents also use a social zone to mingle or eat lunch. *"Yes, you can say that there is often meetings, the meetings are generally held in our office premisses, so I either sit at the office space or in a meeting room, we have corridors and also a social zone that we use up here"*, a respondent told us. Usage pattern is not something that is thought of in the daily life by the respondents.

4.2.5.4 Impact on energy use

Most of the building is automated based a demand control, both light and indoor climate. The office landscape might be an important factor in regard to the automated demand control, one respondent suggests; *"since we have open office solutions, we do not have an individual effect on the energy use in practice"*. The respondent indicates that the impact on energy use is related to users being in the building since the building react in regard to this. Tuning and optimization of the installations and systems in the building is important because of this. There are essentially no way to control lighting and indoor climate except for a small device that one can press plus and minus on. *"It has little impact to try and adjust the indoor climate because of the open landscape solution. Let's say I press minus to turn the temperature down, an other user might press pluss to turn it up again, so you do not have that great impact individually"*, a respondent told us. At the same time, a respondent indicate that trying to adjust the indoor climate up and down by serveral users, will result in an unpredictable rise and lowering of heat and cooling which may impact the energy use at some level instead of a steady temperature based on the automated demand control. All of the employee has a computer that are used during a working day.

All respondent indicate that they have greater control of energy use at home than at work. *"At home you see that cost and usage of energy, and you have to pay for it your self"*, a respondent told us. At Miljøbygget, the respondents do not really think about the energy use, one reason is the automation aspect of the building, and other is that it is not their responsibility to pay for it individually, but rather the organization they work for. All the respondents tell us that they are good at measures to reduce energy use at home, lights are turned off, the temperature is at a reasonable level and so on. At work the respondents do not really think about this, for one, because of the automated system, and also because they have their jobs and tasks to carry out, which have a priority. If the respondents have to work after hours, it is possible to turn on a time function, to turn on lights in just one area of the rented office space, at the same time, the lights will turn on where the user are, so that will not have a big impact according to them. Rather being in the building and moving around will cause an impact on energy use, according to one respondent.

4.2.5.5 Energy use and saving

All respondents say that there is a big focus on energy use and saving in their organization, mostly because this is what they do, working in regard to energy efficiency of buildings. Enova has been in dialog with KLP Eiendom under the development and construction of Miljøbygget, to bring up solutions and to ensure that it is energy efficient. The respondents say that they are aware users and tenants in regard to energy saving and use both in regard to the choice of building and in regard focus on energy use and saving.

To point attention to energy use and saving the respondents have many interesting suggestions. One is that it is imporant to show that it is profitable to have a focus on energy use and saving, both in regard to the building, operation and use. They also say that it is imporant communicate and show how energy saving may be carried out, which measures that needs to be implemented, what the energy use is at and what potential there might be in regard to energy saving measures. Campaigns are something that Enova promote, energy labling is an other aspect. *"It is important to emphasize that energy efficient buildings and measures are a smart choice, we see that there is demand for energy efficient buildings, and that they are appreciated"*, a respondent told us. One respondent suggests that energy efficiency solutions is a quality that needs to be promoted. Another respondent said that it are potentials and barriers related to energy use and savings, especially a barrier associated with the owning and renting relationship; *"It is often difficult to get a owner of a building to invest in energy efficiency because it is the tenant who pays for the energy that profit from it"*. An other aspect is that energy saving is not something that a regular user do at a daily basis. This result in a lack of priority and follow-up. The use of media is a method that makes people aware, especially in relation to energy prices. *"Higher energy prices often lead to a reduced energy use, but this do not always translate to the working environment"*, a respondent told us. This is also related to how important it is for each person, according to a respondent.

The respondents also indicate that automation of buildings will help to reduce energy use. A respondent said that; *"It is important to reduce the impact that user behavior has on energy use"*. An other factor presented by the respondents is that buildings needs to be constructed robust, and that errors and weaknesses in the construction or technical installations are addressed. Passive house solutions is a step in the right direction, since this reduce the need for heating and cooling to a certain extent, according to a respondent. Training of users will probably also have a good effect as long as it is followed up.

4.2.5.6 Gap

The respondents automatically think of the gap between expected and actual energy use as the gap between what is expected based on the design phase and what the building actually use of energy. In the start phase of a building, the system is not trimmed or tuned, and it may take a long time before the technical system is optimized for use. *"It takes typically two or three years before the building is trimmed properly"*, a respondent told us. An other aspect presented by the respondets is that the calculated energy demand is done in regard to a standard that is based on somewhat perfect operation of the building. This is something that do not translate to reality since people are not perfect and make mistakes, according to a respondent. *"Some buildings manage to perform as expected, while other do not"*, a respondent told us. Buildings are not always constructed as intended, building engineering and construction is not always perfect, which may have an impact on the gap, a respondent indicate. In regard to Miljøbygget, all areas was not rented out to begin with, and since it has been more and more users and tenants, it is harder to compare expected and actual energy use from year to year, according to a repsondent.

4.2.5.7 Evaluation of the building

All the respondents describe Miljøbygget as a nice building with good office areas with an exiting use of materials. Generally they like the building well, there have been some cases of poor temperature, but over all there is a good indoor climate that all the respondents are happy with. The respondents like that it is an open landscape, which bring a social aspect to the work place, and also make it easier to communicate. The respondents feel that the office area is pleasantly furnished and that their needs and expectations are met. There was a periode which the ventilation did not work well, which followed by a periode of repairs and noise, which was disturbing, but the respondent looked forward to return to a stable indoor climate. One respondent feel that the sun shading can be improved, there are several instances where the sun shading goes down, even though there is no sun on the facade facing south.

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Chapter 5

Analysis and comparison - the analysis of the master's thesis

5.0 Analysis and comparison

This chapter contains the analysis of this master's thesis. In this chapter we link the theory and literature from chapter 2 to the case study, interviews and findings in chapter 4 and present and analyze the different aspects presented. This analysis is intendent to attempt to answer the research questions and thesis question, and is the basis for the conclusion. The chapter is structured based on chapter two and four with the research questions and thesis question in mind. We start the analysis with a short and concise comparison of Realfagbyget and Miljøbygget as two existing non-domestic buildings, then analyse building types and requirements. Next, we analyse expected and actual energy use - methods and factors. Further, we analyse the management and use of existing non-domestic buildings, then energy efficiency through possible barriers and approaches. Finally, we analyse the gap between expected and actual energy use. We will use references to specific sections in the previous chapters.

5.1 Existing non-domestic buildings

The case study of this master's thesis consists of a study of two non-domestic buildings - Realfagbygget (4.1) og Miljøbygget (4.2). These are two different buildings, especially in terms of the scope, size, stucture, functions, building technical aspects, activity, management, operation and use.

Realfagbygget is a building that primarily supports education and research as part of a university (4.1.2), while Miljøbygget is a building that supports various business aspects of several organizations through rented office space (4.2.2).

Realfagbygget has been in use for 14 years, consists of 62 605 m^2 GFA (4.1.2.1) and is most likely built in regard to the requirements of TEK 97 based on the start of the construction of the building without this being confirmed in the documentation or through the respondents (2.2.2, 4.1.2.6). Miljøbygget is a newer building compared to Realfagbygget and has been in use for over four years. Miljøbygget consists of 16 400 m^2 GFA (4.2.2.1) and is built in regard to the requirements of TEK 07 (4.2.2.6). There is a big difference in size of the two buildings, Realfagbygget is 46 205 m^2 GFA larger, which is almost four (3,8) times as large as Miljøbygget. This also represents a significant difference in relation to the extent of technical installations and systems necessary to operate the buildings (4.1.2.6, 4.2.2.6). This will be factors which will contribute in a big difference in energy demand and usage in regard to the two buildings. The numbers of users will also play a role, as the Realfagbygget has a significantly greater activity than Miljøbygget. Realfagbygget has approximately 3 200 users daily (4.1.2.10), while the Miljøbygget is not close to this user activity, without us having received any details of a specific number of users at Miljøbygget (4.2.2.10).

The size of the buildings is also expressed through the project costs where the difference is the whole of 1 075 600 000 NOK (4.1.2.5, 4.2.2.5), with Realfagbygget as the most expensive. This represents a difference of 6 605 NOK per m^2 GFA (4.1.2.5, 4.2.2.5), where Miljøbygget is the most cost effective per square meter. Realfagbygget is owned by the property management department at NTNU, while Miljøbygget is owned by KLP Eiendom.

Realfagbygget and Miljøbygget is located relatively close to each other (4.1.2.3, 4.2.2.3) with a walking distance of about five minutes between them. This indicates that the two buildings have the same climate and outdoor temperature.

Both of the buildings are characterized by an extensive use of place molded concrete and the use of glass (4.1.2.6, 4.2.2.6), each with its own architectural expression and specific use of various materials and details to support it (4.1.2.1, 4.2.2.1). The energy commodities which is mainly used for both buildings is electricity and district heating (4.1.2.6, 4.1.3.2, 4.2.2.6). Although, Realfagbygget has a wider scope of technical installations (4.1.2.6), Miljøbygget is more modern, especially when it comes to operating the building by the total use of demand controlled systems (4.2.2.6). This suggests that Miljøbygget is more automated and possibly more intelligent in regard to the theory and literature (2.5.4). Both buildings are equipped with energy monitoring devices, BMS and EMS. We will get back to this later in the analysis.

The buildings have different rooms and areas, linked to the various functions in relation to the buildings. Realfagbygget consisting mostly of auditoriums, laboratories, classrooms and reading room (4.1.2.1), while Miljøbygget consists mostly of office space for rent (4.2.2.1). Both buildings have common areas, canteens and meetings rooms (4.1.2.1, 4.2.2.1), while Miljøbygget also have an auditorium and Realfagbygget has lots of offices, this can be seen as common features.

Both Realfagbygget and Miljøbygget is described as being good and nice buildings by the users interviewed (4.1.5.7, 4.2.5.7). Realfagbygget recieves positive mention in relation to the modern expression, as well as the open, convenient and bright premises. Some of the offices could have better solutions, while the activity at Realfagbygget often leads to occupied rooms (4.1.5.7). Miljøbygget receives positive mention in relation to the exciting use of materials and the choice of open landscape solutions (4.2.5.7). Both buildings ensures that users are satisfied and have their needs met, although it is mentioned that there have been problems with poor air and temperature of different areas of the two buildings (4.1.2.1, 4.2.2.1). This indicate that the buildings have potential for improvement in terms of better adaptation towards the users.

5.1.1 Building types

In regard to the theory and literature it is described that there has been developed at standard called NS 3457-3:2013 to organize and classify buildings. Both Realfagbygget and Miljøbygget can be defined as a building in regard to the standard (2.1). Based on this standard it is possible to classify the building type of Realfagbygget and Miljøbygget. The building's function is the most important factor to classify a building. We will base the classification on the room functions according to the zone part of the classification system (2.1). Realfagbygget's main function is primarily education and research with other sub-functions related to this (4.1.2). Based on this, Realfagbygget can be classified with main function 6 (educational, sporting and culture building) on the one-digit level (2.1). We have not been able to get a specific overview of the area or room functions of the building, but there is mainly room area with education purposes at a university level. There is also offices, laboratories and other areas with research or other purposes (4.1.2). Based on this, Realfagbygget can be classified with building group 62 (university and college building) on the two-digit level (2.1). Further, Realfagbygget can be classified with building type 621 (building with integrated functions, auditoriums, reading rooms ect.) on a three-digit level (2.1).

Miljøbygget's main function is primarily an office function with other sub-functions related to this (4.2.2). Based on this, Miljøbygget can be classified with main function 3 (office and commercial building) on the one-digit level (2.1). We have not been able to get a specific overview of the area or room functions of the building, but there is mainly room area with office purposes. There is also other areas with other purposes (4.2.2). Based on this Miljøbygget can be classified with building group 31 (office building) on the two-digit level (2.1). Further, Miljøbygget can be classified with building type 311 (office building) on a three digit level (2.1).

Based on this we can define Realfagbygget as a university and college building with integrated functions and Miljøbygget as an office building. None of these two buildings have residental purposes and therefore fit the term of an non-domestic building presented in section 1.1, the first criteria in the systematic selection method and the title to the master's thesis.

5.1.2 Energy requirements

In regard to the theory and literature there has been released several technical building regulations in relation to the construction quality of buildings over the years - often called TEK with the year it was released after (2.2). A clear factor in these technical building regulations is the increased focus and strictened requirements in regard to energy (2.2). Based on simulations, the net specific energy demand per TEK-level which is based on ideal conditions has been reduced from 271 kWh/m^2 (TEK 49) to 136 kWh/m^2 (TEK 10) for office buildings and from 255 kWh/m^2 (TEK 49) to 144 kWh/m^2 (TEK 10) for university and college buildings (2.2.2). Estimates for more real conditions of delivered energy per TEK-level also display a high reduction from TEK 49 to TEK 10 (2.2.2). The current requirements in TEK 10 for total net energy demand is 150 kWh/m^2 heated UFA per year for office buildings and 160 kWh/m^2 heated UFA per year university and college buildings, which is far higher than the total net energy demand for passive house or low energy buildings (2.2.1, 2.2.3).

Even though the energy requirements has been reduced greatly to ensure more energy efficient buildings, there is still the possibility and risk that energy use in buildings is higher than expected - based on expected and actual values (2.2). New technical requirements is planned from 2015 and there is suggested several stricter requirements towards a passive house level and improvements to ensure that buildings meet the requirements through simpler methods in regard to a calculation and measurement aspect (2.2.4).

There are several possible reasons for why buildings do not meet the requirements. The theory and literature mention technical installations, lack of focus, poor management and operation, and unpredictable building and area development as some of the reasons (2.2) among others (2.4, 2.5, 2.6). These reasons certainly constitutes some of the factors in regard to that energy requirements not always are met, along with the calculation of expected performance.

This may indicate that the focus in relation to the technical requirements are aimed towards new buildings and does not follow the buildings development. Technical requirements can help to ensure the quality of new buildings - but how well does it translate to existing buildings of various ages, built according to older requirements? The relevance of new technical requirements may be seen as important for new buildings, but existing buildings are not required to fulfill the new requirements. This indicates further that through stricter requirements we get more energy efficient buildings in the long term, but that existing buildings in general will be less energy efficient compared to new buildings, as long as they are not being renovated and reconstructed to fit the new requirements, which is often too expensive or not a priority (2.5.5).

It is clear that Miljøbygget is built with a better compatibility for energy efficiency than Realfagbygget - both in regard to newer requirements (based on the age of the buildings) and focus in the design, construction and solutions (4.1.2, 4.2.2), even though there is an increased focus on Realfagbygget both in terms of technical developments, management and operation (4.1.4). Realfagbygget (university and college building) should have a specific delivered energy of 239 kWh/m^2 based on age and TEK 97 (4.1.2.1, 2.2.2), while Miljøbygget (office building) should have a specific delivered energy of 157 kWh/m^2 based on TEK 07 (4.2.2.6, 2.2.2). For these figures there is added conditions to provide a more realistic aspect (2.2.2). The difference between these two figures for Realfagbygget and Miljøbygget is 82 kWh/m^2, which is higher than the difference between the energy limits for total net specific energy demand which is 57 kWh/m^2 (2.2.2) based on TEK 97 for Realfagbygget and TEK 07 for Miljøbygget. It is also a factor that different building types have different figures in addition to the difference between the technical requirements (2.2.2). Miljøbygget is constructed to have even better performance then TEK 07 (2.2.2) with a net energy demand of 110 kWh/m^2 and a delivered energy of 83 kWh/m^2 (4.2.2.6).

The theory and literature suggests that the development in energy use for non-domestic buildings will depend on future technical regulations and if the buildings meet them in regard to the development of the buildings (2.2). It is important that the technical requirements ensure the quality and energy efficiency of new buildings, but in this aspect it is also important to evaluate existing buildings in relation to the new technical requirements to further improve energy efficiency for existing buildings aswell. To what extent must necessarily be discussed in regard to pros and cons, and in regard to what is possible and realistic to implement. This will most likely lead to great challenges, great opposition and will be difficult to implement.

5.2 Expected energy use

Through the literature study conducted, we mapped methods used to calculate buildings energy performance (2.3.1), requirements (2.3.2) and label (2.3.3). We expected that the methods mapped not only were used in calculations for new buildings, but also in regard to existing buildings. Through the interviews we learned that either the facilities managers at Realfagbygget (4.1.4.4), nor the facilities managers at Miljøbygget (4.2.4.4) used the methods presented in the theory and literature (2.3) to calculate the expected energy use, even though the methods to calculate energy performance are applicable for this task (2.3.1). The theory and litterature also states that the calculations which is based on standarized figures not always translate to reality (2.3.1). Based on this, we have decided to categorized the calculation methods based on being an ideal or realistic calculation method. The expected energy use for the two cases is analysed in a separate sub-section.

5.2.1 Ideal calculation methods

The theory and literature present a standard called NS 3031:2007 for the calculation of energy performance (2.3.1). This standard is used for many purposes, to assess if a building meet the requirements in the technical building regulations or in the passive house standard NS 3701:2012, to document theoretical energy requirements, and to calculate the energy demand, performance and use in new or existing buildings (2.3.1, 2.4.1). The standard is also used in the process to assess an energy label for buildings (2.3.3). The standard NS 3031:2007 depend on a range of other standards to carry out the different methods and calculations, which is selected based on various cases (2.3.1). There is both a theoretical energy demand and a actual energy demand, where the actual energy demand most is accurate because of the use of less standarised figures and for being based on measures along with statistical figures (2.3.1). There are several calculations tools that are based on the standard NS 3031:2007. One common calculation tool or simulations tool for buildings is SIMIEN, while there is also used excel sheets (2.3.1).

The weakness with these calculation methods to determine energy demand and performance is the use of standardized input data (2.3.1), which often is based on ideal conditions, even measured values may be described as ideal. It might be possible to simulate both ideal and real energy conditions with standardized and measured values, the problem is to fit users into the ideal conditions. The users do not always fit in the calculations, because the users are less predictable (2.6). For these reasons we will describe the standard NS 3031:2007 with related methods and figures as ideal calculation methods. This analysis is also supported by a respondent interviewed implying that standardized figures are not realistic (4.2.4.4) This analysis will reflect futher on both the calculation of energy requirements and the energy labeling system which use the NS 3031:2007 as a part of the assessment.

In regard to energy label, there has not been assessed one for Realfagbygget (4.1.3.4), but there has been assessed a energy label for Miljøbygget (4.2.3.4). Miljøbygget has received energy label B with a light green color (4.2.3.4). In regard to the theory and literature this indicate that Miljøbygget should have lower than or equal of 115 kWh/m^2 energy delivered per m^2 heated UFA and heating rating with a proportion of 47,5 percent or lower of electricity and fossil fuel (2.3.3). This might translate to the description of the building (4.2.2.6), but how well it translate to the actual energy use is an is another matter. We will get back to this in the analysis of actual energy use.

5.2.2 Realistic calculation methods

While the actual energy demand may be descrbibed as a buildings real energy demand and may grasp the reality to an extent (2.3.1), there is still a problem with users not fitting in to this calculation (2.6). To implement the users into the calculations of expected energy use to a further extent, we will related to the calculations models presented in the conducted interviews at Realfagbygget (4.1.3.1, 4.1.4.4) and Miljøbygget (4.2.3.1, 4.2.4.4).

In the calculation method for expected energy use presented for Realfagbygget (4.1.3.1, 4.1.4.4), there is used historical (empirical) energy data which is the actual energy use for the previous years. The calculation method for expected energy use is calculated by taking the average of actual energy use of the three last years. Temperature correction is not performed. To use this calculation method to determine expected energy use is realistic because it is based on a average of actual use, based on the building, management and operation and the users in it. There are however strengths and weaknesses with this calculation method. The primary strength is that the figures used is based on actual and real conditions, while the use of average calculation takes several years into consideration and therefore can reduce the factors that impact or influence the energy use an unusual amount a specific year. A good example is the outdoor temperature which can be described as random. There are several factors that may impact, where the specific degree may be different from year to year (2.4.3). The weaknesses of this method is that there is not used temperature correction (2.4.3), which could have supported the method and comparison potential. An other weakness with this calculation method is the lack of improvement, improved energy efficiency and development. These are factors that are directly not supported with this calculation method. If an organization such as the operation department at Realfagbygget constantly develop to be a better facilities management organization (4.1.4.3, 4.1.4.6) and there is made building technical improvements, this should affect the expected energy use to some degree, but the development and improvement factor is partly neutralized by the use of average calculation in the method. Generally speaking, expected energy use will be based on what has happened before, but not what is happening now.

In the calculation method for expected energy use presented for Miljøbygget (4.2.3.1, 4.2.4.4), there is also used historical (empirical) energy data. The calculation method is very similar to the method used a Realfagbygget, but instead of using the average of the three last years, only the last year is used to calculate the expected energy use. Temperature correction is performed. This calculation has the same strength as Realfagbygget in regard to that the figures used is based on actual and real conditions. However without the use of average calculation, the expected energy use will just follow the last years actual energy use with a temperature correction and the potential of factors that may influence a specifically high amount one year may lead to wrong expectations. The development and improvement aspect is also not taken into consideration for this calculation method, but the facilities management at Miljøbygget may adjust in regard to changes in the tenant mix (4.2.4.4, 4.2.4.3). There is also set energy goals at Miljøbygget, but this is not a part of the calculation of expected energy use (4.2.4.4), but would rather be expressed in the actual energy use. For both Realfagbygget and Miljøbygget it is the operators of the facilities managers that perform calculations of expected energy use (4.1.4.4, 4.2.4.4). This is probably a positive factor, since it is them who monitor the building and follow the daily operations.

5.2.3 Expected energy use for the cases

Based on the calculation method for expected energy use for Realfagbygget, we have calculated the expected energy use from 2006 to 2014 (4.1.3.1). The calculation methods presented in the theory and literature (2.3) is not used because we wanted to use the actual calculation method which is used by the facilities management at Realfagbygget, but display calculation methods which is used for several purposes in regard to non-domestic buildings in general. In the calculated expected energy use (4.1.3.1), we can see that the calculations vary from year to year both with a positive and negative development. The expected energy use had a positive development from 2008 to 2010, but took a negative turn from 2010 to 2013. From 2013 to 2014 there has been a high reduction in regard to the expected energy use. The expected energy use is a direct result of the previous actual energy use and the potential impact factors influencing it. The expected energy use varies in between the scope of 16 068 252 kWh (lowest) and 17 129 138 kWh (highest). The difference between is 1 060 886 kWh. Based on the GFA of the building (4.1.2.1), this results in a scope of the lowest and highest of 256,66 kWh/m^2 and 273,61 kWh/m^2.

Based on the calculation method for expected energy use for Miljøbygget, we have calculated the expected energy use from 2011 to 2014 (4.2.3.1). As we described for Realfagbygget, we have not used the calculation method presented in the theory and literature (2.3) for the same reasons. In the calculated expected energy use (4.2.3.1), we can see that the calculations have had a negative development from 2011 (which is based on the delivered energy demand (4.2.2.6, 4.2.3.1)) to 2013. The expected energy use from 2012 to 2014 is based on the actual energy use as described (4.2.3.1). From 2013 to 2014 there has been a positive development. The expected energy use varies in between the scope of 1 361 200 kWh (lowest) and 1 866 000 kWh (highest). The difference between is 504 800 kWh. Based on the GFA of the building (4.2.2.1), this results in a scope of the lowest and highest of 83 kWh/m^2 and 113,78 kWh/m^2.

We can see that there are higher variations of the expected energy use for Realfagbygget than for Miljøbygget, but this is not a good basis for comparison because of the different methods (4.1.3.1, 4.2.3.1), different buildings (4.1.2, 4.2.2), difference in age between the buildings (4.1.2.1, 4.2.2.1) and different management (4.1.4, 4.2.4) and use (4.1.5, 4.2.5). There is also a much better expected energy use per m^2 for Miljøbygget than for Realfagbygget.

5.3 Actual energy use

The analysis of actual energy use is structured in a sub-section for monitoring and measurement, where we analyse how monitoring and measurement of energy use may be performed according to the theory and literature (2.4) and how it is performed for Realfagbygget (4.1.4.5) and Miljøbygget (4.2.4.5). There is also a sub-section for possible impact factors based on the theory and literature (2.4.3) and possible impact factors in relation to Realfagbygget (4.1) and Miljøbygget (4.2). Finally, there is a sub-section where we analyse the actual energy use for the two cases (4.1.3.2, 4.2.3.2).

5.3.1 Monitoring and measurement

The theory and literature present seven main groups of energy commodities (2.4). Of these seven there are two commodities that are mainly used at both Realfagbygget and Miljøbygget, which is electricity and district heating (4.1.2, 4.2.2). The theory and literature describe electricity as the main energy carrier for university and college buildings and office buildings. This is also the case for Realfagbygget and Miljøbygget. Realfagbygget has a proportion of electricity between 64,69 (2007) and 74,80 (2011) percent, based on the lowest and highest proportions (4.1.3.2). Miljøbygget has a proportion of electricity between 73,24 (2011) and 74,21 (2012) percent, based on the lowest and highest proportions (4.2.3.2). Figure 5 (2.3) suggests that university and college buildings use more energy per m^2 than office buildings, which translate to Realfagbygget and Miljøbygget as described in section 5.2.3 based on the expected calculations. Miljøbygget is at the same time more optimized towards energy efficiency which affect this further.

The theory and literature present a standard called NS-EN 15603 which may be used to assess and determine total energy use and performance. NS 3031:2007 may also be used to measure and verify energy use (2.4), or to calculate expected energy use based on measured values (2.4.1). Based on the interviews (4.1.4.5, 4.2.4.5) there is nothing suggesting the use of these standards in regard to monitoring and measurement of energy use, but rather depend on installed technology and systems.

In regard to the theory and literature, measurement of energy use require a BMS or separate monitoring devices. The monitoring structure should reflect a proposed structure in NS 3031:2007 (2.4.1). We could not find out how the measurement structure of Realfagbygget (4.1.4.5) and Miljøbygget (4.2.4.5) specifically is to compare it with the proposed structure. Realfagbygget has installed between 400 and 500 energy monitoring devices which is installed on different units of the technical installations in the building (4.1.4.5), while Miljøbygget has installed between 60 and 80 energy monitoring devices divided by ventilation, lighting, heat pumps among others (4.2.4.5). The amount of energy monitoring devices suggest the difference of the extent of technical systems in the two buildings. The theory and literature highlights the importance in regard to that the energy monitoring devices can communicate data (2.4.1). Through the interviews for the two buildings (4.1.4.5, 4.2.4.5) it is said that all the energy monitoring devices can communicate data automatically, which suggest that they are up to date (2.4.1). Both Realfagbygget (4.1.4.5) and Miljøbygget (4.2.4.5) has both a BMS and EMS, which the theory and literature describe as an important tools to have on overview and control of the buildings and energy data (2.4.1). Based on this, and the interviews (4.1.4.5, 4.2.4.5) we can say that both Realfagbygget and Miljøbygget has the needed installations and systems to control, measure and monitor the buildings and energy use on a daily basis. Both Realfagbygget (4.1.4.5) and Miljøbygget (4.2.4.5) has a high focus on monitoring of the building to ensure energy efficiency.

5.3.2 Impact factors

There are several impact factors which affect a non-domestic buildings energy use presented in the theory and literature. These are factors that impact a building through its life cycle (2.4.2). A building will generally be affected by different factors before and after the building is completed and ready for use (2.4.2). Because we study existing non-domestic buildings in this master's thesis, we will shortly summarize the impact factors which is relevant before the building is completed, and rather focus on the impact factors relevant for the management and use phase.

The impact factors relevant before the building is completed is based on the choices of localization, design, construction, solutions, installations and the performance of the construction work, aswell as the current building technical requirements when the building is constructed (in regard to the age of the building). This will lay the basis of a building, which will follow the building through its life. The energy efficiency and use will depend on this (2.4.2).

After a building is completed, it is ready for use to fulfill its functions and intentions. The theory and literature describe facilities management as an important factor of a building and its energy efficiency (2.4.2). This is because the management, operation and maintenance of the building will affect how the building is handled, preserved and developed - and if this is done as optimal and correct as possible (2.4.2). There are several challenges related to this - both predictable and unpredictable. The facilities management depend on expertise, experience, focus, motivation and leadership, among other factors, to ensure good management, operation and maintenace of the various aspects of a building (2.4.2, 2.5.4). These qualities of facilities management is not always at a satisfactory level (2.4.3, 2.5), making it unpredictable. The outdoor temperature is a rather unpredictable challenge, especially in a long term perspective, and is described as the most significant factor for the energy development in buildings in the theory and literature in regard to heating and cooling (2.4.2). An other challenge is the users of the building and their behavior (2.4.2). While a user individually sometimes can be partly predictable, the challenge is to manage several or many users. This is because they are different - both through their needs, actions, motivations, preferences and expectations, among other factors (2.6). The users is an impact factor for energy efficiency through the usage of buildings (2.3.2, 2.6). Energy costs is an other impact factor, basically because the focus on energy use relate to the cost (2.4.3).

Almost all of these impact factors where mentioned through the interviews conducted for Realfagbygget (4.1.4) and Miljøbygget (4.2.4). The importance of talented and focused people to plan and carry out work in relation to facilities management (4.1.4.5, 4.1.4.5, 4.2.4.3, 4.2.4.5), issues in relation to the outdoor temperature (4.1.4.5, 4.2.4.5), challenges in regard to the users or tenants (4.1.4.5, 4.2.4.5), but also the importance of the building and its development (4.1.4.6, 4.2.4.6) are mentioned. This indicate that the facilities management for both Realfagbygget and Miljøbygget are aware of potential impact factors related to the energy efficiency, that there are similarities in their understanding, and that there are similarities towards the theory and literature.

5.3.3 Actual energy use for the cases

Actual energy use for Realfagbygget is measured by energy monitoring devices and communicated to a BMS and gethered in a EMS (4.1.3.2). Figure 18 display clear variations for each month and year in regard to actual energy use (4.1.3.2), but the general curves for each year indicate that there is higher energy use in the first and fourth quarter, while there is lower energy use in the second and third quarter. This can be explained by the outdoor temperature, since the energy use develope in regard it (2.4.2). It is generally colder in the first and the fourth quarter than the second and third. This can also be explained by lower activity during summer, because of summer vacation, espesially for students who generally attend from August to June. Figure 19 show that the actual energy use was rather stable from 2003 to 2007, followed by a drop of lower energy use in 2008 (4.1.3.2). From 2008 to 2010 there is a high increase in actual energy use (4.1.3.2). In figure 7, we can see that there was a large negative temperature deviation from the average annual temperature, suggesting that it was a cold year (2.4.2), which again can explain the increased actual energy use. From 2011 to 2013 the actual energy development is more stable (4.1.3.2). The lowest actual energy use was in 2008, where the actual energy use was 15 324 010 kWh (4.1.3.2). The highest actual energy use was in 2010, where the actual energy use was 18 853 015 kWh (4.1.3.2). Based on the GFA for Realfagbygget (4.1.2.1), this result in a actual energy use of 244,77 kWh/m^2 for the lowest (2008) and a actual energy use of 301,14 kWh/m^2 for the highest (2010). Based on the UFA for Realfagbygget (4.1.2.1), this result in a actual energy use of 383,10 kWh/m^2 for the lowest (2008) and a actual energy use of 471,32 kWh/m^2 for the highest (2010). This is high compared to the estimates presented in the theory and literature for TEK 97 for university and college buildings (2.2.2). The actual energy use per m^2 GFA can however relate to the value for university and college building, presented in figure 5 (2.4). The calculations are not based on the same conditions. Respondents describe the actual energy use as varying and relate this to the (increasing) user activity, lack of focus and priority, lack of expertise and experience in the management, operation and maintenance, the outdoor temperature, different rooms such as laboratories, technical installations, but also improvements of the building (4.1.4.5).

Actual energy use for Miljøbygget is measured by energy monitoring devices and communicated to a BMS and gethered in a EMS and then reported to Entro (4.2.3.2). Figure 26 display some variations for each month and year in regard to actual energy use (4.2.3.2), although the actual energy use for 2012 and 2013 is relatively similar until september. From september the actual energy use for 2013 is lower then both 2011 and 2012 (4.2.3.2), and is at the same level as the actual energy use in the second and third quarter, which is inconsistent with the assumptions described for Realfagbygget, about the forth quarter. Generally, the actual energy use for Miljøbygget (4.2.3.2) show that there is higher energy use in the first and fourth quarter, which is similar to Realfagbygget. This support the assumptions about the impact of the outdoor temperature explained for Realfagbygget. Figure 27 show an increased actual energy from 2011 to 2012, with a decrease from 2012 to 2013 (4.2.3.2). The lowest actual energy use was in 2011, where the actual energy use was 1 591 000 kWh (4.2.3.2). The highest actual energy use was in 2012, where the actual energy use was 1 866 000 kWh (4.2.3.2). Based on the GFA for Miljøbygget (4.2.2.1), this result in a actual energy use of 97,01 kWh/m^2 for the lowest (2011) and a actual energy use of 113,78 kWh/m^2 for the highest (2012). This is rather good results compared to the simulations and estimates presented in the theory and literature for TEK 07 and for TEK 10, and also for the simulations for low-energy buildings (2.2.2). The actual energy use per m^2 GFA is also much better than the value for office buildings, presented in figure 5 (2.4). All the calculations are not based on the same conditions. Based on the actual energy use and proportion of electricity (4.2.3.2), we can assume that Miljøbygget fit energy label B with light green color (2.3.3), since energy delivered per m^2 heated UFA is lower than the calculation based on GFA, which was used to calculate actual energy use per m^2 for Miljøbygget on the previous page. Since Miljøbygget use electricty and domestic heating as the main energy commodities (4.2.2), and based on the proportion of electricity use for Miljøbygget (4.2.3.2), which is based the total electricity use and not just the electricity used for heating we can also assume that the light green color is correct. Respondents describe the actual energy use as higher than expected and relate this to a break-in periode to get the optimal tuning, the varying tenant mix, building technical limitations, the outdoor temperature, and the users with different needs and expectations (4.2.4.5).

The actual energy use is varying each year for the two buildings, and there are mentioned different factors impacting the actual energy use for Realfagbygget and Miljøbygget. How each factor specifically impact it is harder to imply, especially in relation to the management and use.

5.4 Management and use

Facilities management is described as a growing discipline that shall support the primary activities of organizations by integrating processes and services in the theory and literature (2.5.1). Users - the different people using the buildings is described as a difficult and imporant aspect in regard to buildings because of the varying user behavior of each individual user (2.6). The analysis of management and use is split between facilities management and building use and behavior, where we analyse the findings from Realfagbygget and Miljøbygget in regard to the theory and literature.

5.4.1 Facilities management

The facilities management at Realfagbygget is split between a property management department and a operation department (4.1.4.2). The property management department and the operation department is the provider of the facilities services to support the primary activities at Realfagbygget and NTNU in regard to figure 8 (2.5.1). NTNU is the client, the tenants (the departments, sections and faculties) are the customers and the end user is mainly students, staff and employees in regard to the same figure (2.5.1, 4.1.2.10). The property management department can be described as a strategic and tactical department (4.1.4.2, 2.5.1), even though they are described as too operational according to a respondent (4.1.4.3). The operation department can be described as tactical and operational, but is also involved in the strategic processes. The facilities management is mainly a totalt internal service provider, with exception of some external outsourced services (2.5.1, 4.1.4.2, 4.1.4.3). The facilities management organization at Realfagbygget and NTNU fit the localised site model described in the theory and literature (2.5.2, 4.1.4.2), where the headquarter is located on campus Gløshaugen close to Realfagbygget (4.1.4.2). The degree of decentralization may be assessed as low (2.5.2, 4.1.4.2). The facilities management as a whole may be considered as a major FM organization that is well organized and structured with various responsibilities and functions of the various areas and buildings of NTNU (4.1.4.2, 4.1.4.3). The three facilities managers interviewed has different positions and act on different levels, where the operation chief act on a strategic to tactical level, the operation manager on a tactical and operational level and the site manager mainly operate on a operational level (2.5.1, 4.1.4.3). Based on this it is clear that they have a slightly different understanding of the organization and overview of management, operation and maintenance in regard to their position, responsibilities and tasks (4.1.4.2, 4.1.4.3). The goals and objectives are most clear on a strategic to tactical level, and reflected upon less at the operational level based on the respondents (4.1.4.3). The facilities management at Realfagbygget and NTNU is described as continuously improved and developed to become as good as possible (4.1.4.3, 4.1.4.6) - towards best practice (4.1.4.3, 2.5.3). There are implemented several objectives and measures to ensure this. Examples of this is to strengthen and develop the employees and the workplace, implementing best practices and clear plans, get a better understanding of how the primary activities may be supported, as well as having a focus on energy saving and understanding of it (4.1.4.3). The theory and literature describe benchmarking as an important activity to achieve best practice (2.5.3). This is used and implemented in the facilities management at Realfagbygget and NTNU to support their development and improvement (4.1.4.3). The benchmarking has helped to find challenges and areas for improvement, such as poor overview of the various buildings, poor overview of which tasks are performed, and lack of communication (4.1.4.3).

The facilities management at Miljøbygget is generally split between a technical department and a management department of KLP Eiendom (4.2.4.2). The technical department and the management department is the provider of the facilities services to support the primary activities at Miljøbygget in regard to figure 8 (2.5.1). KLP Eiendom may be considered as the client that owns the building, while the tenants (the organizations that rent office area) are the customers and the end user is mainly the organization's employees in regard to the same figure (2.5.1, 4.2.2.10). The technical department can be described as a strategic, tactical and operational deperatment (4.2.4.2, 2.5.1). The management department can be described as mainly strategic and tactical (2.5.1, 4.2.4.2, 4.2.4.3). There is described a degree of outsourcing (4.2.4.2). The facilities management organization at Miljøbygget fit the localised site model described in the theory and literature (2.5.2, 4.1.4.2), where the headquarter is not located at Miljøbygget, but there are facilities managers stationed there (4.2.4.2, 4.2.4.3). The degree of decentralization may be assessed as higher compared to Realfagbygget (2.5.2, 4.2.4.2, 4.2.4.3). The facilities management based in Trondheim may be considered as a middle sized FM organization with a rather flat structured where the organization is based on various responsibilities and tasks in regard to different buildings (4.2.2.9, 4.2.4.1, 4.2.4.2, 4.2.4.3). The to facilities managers interviewed has different positions and act on different levels, where the property manager act on a strategic to tactical level and the operating technician act on a primarily operational level (2.5.1, 4.2.4.3). As for Realfagbygget, there is a different understanding and overview of the management, operation and maintenance in regard to their position, responsibilities and tasks (4.2.4.2, 4.2.4.3). The goals and objectives are most clear on a strategic to tactical level, and reflected upon less at the operational level based on the respondents (4.2.4.3). The facilities management at Miljøbygget is also making efforts to improve and be a good FM organization, through updated plans and goals both for the organization, but also for the individual employees, with a high focus on monitoring and measurement in regard to Miljøbygget and at the same time try to provide the best premises for the tenants and users (4.2.4.3). They also use support from Entro to keep an overview of the energy use (4.2.4.5), which may be considered as smart in regard to the intentions of the building (4.2.2.1).

5.4.2 Building use and behavior

In regard to the theory and literature, users (people) are unpredictable because of the their behavior which is described as one of the most complex processes in regard to buildings, energy use and efficiency (2.6). It is hard to predict how users will act and use a building, and how their choices, preferences, needs and reasons play in regard to this (2.6). Each user may have different behavior and therefore different user patterns, which also lead to different behavior in regard to energy use and efficiency (2.6). An important factor presented in the theory and literature is that users have different responsibilities in regard to a non-domestic building than in their own home, especially in regard to a financial responsibility (2.6). This can be one factor which lead to higher energy use, since they do not have the same responsibility for their own use of energy. At the same time, there is a challenge that even though users want to support and focus on energy efficiency, they are not aware of how they may contribute (2.6). To reduce the impact of users and their behavior, there is suggested that automated solutions and technology may be important, but that this depend on the users acceptance and knowledge in regard to this (2.6). This indicate the technology is not a solution in it self, but depend on the users aswell (2.6). Better area management is also a mentioned measure (2.6), but it may be discussed that this also will depend on the users like with the technology.

In regard to the findings based on the interviews of users at Realfagbygget, we can see that there are different users - both through their position at Realfagbygget and NTNU (4.1.5.1), but also in regard to their building use and localization (4.1.5.1, 4.1.5.2). It is clear that the building use depend on the users agenda, schedule and plans. In regard to the students, this varies even greater based on each year and the subjects they are taking (4.1.5.2, 4.1.5.3). These factors translate to the user pattern and it is clear that the users have different user patterns (4.1.5.3), which support the theory and literature (2.6). A respondent suggest that students move and use the building as a group (4.1.5.3), which we think is an exciting finding, since students often go to lectures, and meet before they do something, but users also use the building individually (4.1.5.3). Based on all the respondents, it is clear that energy saving and efficiency is not a priority or focus in their daily use of Realfagbygget. This may translate to a low awareness in regard to energy use and efficiency, which the findings also suggest (4.1.5.4, 4.1.5.5). This can be related to poor communication, information, visibility, motivation, follow-up and lack of measures - towards the users (4.1.5.5).

In regard to the findings based on the interviews of users at Miljøbygget, we can see that there are different users (4.2.5.1), but not as different as the users at Realfagbygget. The reason for this might be that they have similar location and similar tasks to some degree (4.2.5.1). The building use (4.2.5.2) is also more concise compared to Realfagbygget. The reason for this might be a smaller building which limit the building use to some degree, aswell as they are employees of the same tenant of Miljøbygget (4.2.5.1, 4.2.5.2). The building use is however related to daily rutines, plans, schedule and agenda based on their position which translate to their usage pattern (4.2.5.1, 4.2.5.3). The usage pattern is not that different, but is not someting the users think about in their daily life (4.2.5.3). Through the users position and organization, they have a higher awareness and understaning about energy use and efficiency (4.2.5.4, 4.2.5.5), but the findings suggest that they use the automatic demand control and the open landscape office as an excuse, since they feel that they do not have a big impact on the energy use because of it, and prioritize their jobs and tasks (4.2.5.4). A respondent think the impact is related to users being in the building, rather than what they do (4.2.5.4), which again relate to the automated demand control. In regard to the theory and literature, it may be assumed that the users feel that the building and technology reduce their impact on energy use (2.6), but it is still influenced by the user in some form (4.2.5.3). There is also indication towards that they have a higher focus on energy use at home (4.2.5.4). A higher awareness of energy efficiency and use is also indicated through their suggestions of measures and attention towards energy saving and energy efficiency (4.2.5.5). We have however no evidence that these factors translate to other users of the building, and it may be assumed that there is lower awareness in other organization.

5.5 Energy efficiency

The theory and literature present that it is increased attention towards energy efficiency in a large perspective. An example of this is stringent regulations (2.5.4). There is a focus on smarter and more intelligent buildings with more complex and energy consuming technology to support the users. Buildings should last long, and there is an increased focus on a lifecycle perspective and the buildings adaptability (2.5.4). There is a potential in regard to existing buildings, while it is easier to achieve energy efficiency in newer building in regard to the theory and literature (2.5.5). Based on this we can assume that there is a high focus on buildings, technology and solutions, but how well does energy efficiency translate to management and use of buildings? The theory and literature suggest that energy efficiency is more than a challenge in regard to buildings and technology (2.5.4). We have structured this section in two sub-sections - barriers against energy efficiency and approaches for energy efficiency.

5.5.1 Barriers

The theory and literature suggests several barriers of different types, which is focused towards existing buildings (2.5.5). These barriers is directed to various conditions. There are barriers in regard to the building based on the age, related costs, interests, visible profits, energy costs, a long-term perspective, visibility, communication and the owner and tenant relationship (2.5.5). There are barriers in regard to government and regulations (2.5.5). There is also barriers in regard to management, operation and maintenance through lack of knowledge, expertise, leadership, communication, a long-term perspective and negative attitudes (2.5.5). For users the barriers relate to awareness, that they are comfort-seeking, knowledge, corporate culture, visibility and communication (2.5.5). The barriers will have different degrees in regard to breaking them down, which depend on control (2.5.5).

Based on the interviews at Realfagbygget there is indication of several barriers. One is the limitations in the building it self and costs associated to rebuild, repair and maintain the building, which is beginning to become more necessary. This will result in new tuning periodes (break-in periods) towards optimization (4.1.4.6). An other is the lack of people with satisfactory expertise and experience to manage and operate it sufficiently (4.1.4.5). Barriers in regard to communication, information, awareness, priority, focus and follow-up is also present, both for managers and users (4.1.4.3, 4.1.4.5, 4.1.5.4, 4.1.5.5). Realfagbygget is always open for the users, which makes it harder to manage and operate, while the activity is hard to predict (4.1.4.6). This is also a barrier, and can relate to the users and their behavior (4.1.5). We can see that there are many barriers presented in the theory and literature that is present at Realfagbygget.

Based on the interviews at Miljøbygget there is also indication of some barriers. One barrier is the tenants and the tenant mix, which can be hard to manage (4.2.4.3, 4.2.4.5). As a result there is a barrier in regard to the owner and tenant relationship (4.2.4.5, 4.2.5.5). We can also assume that there is some form of barrier in regard to priority and focus, especially in regard to the users (4.2.5.4, 4.2.5.5). While there also can be a barrier in regard to the dependability of the automatic demand control of the building - both in regard to the users and the operation of the building (4.2.4.5, 4.2.5.4, 4.2.5.5). We can see that there are less barriers presented in the theory and literature that is present at Miljøbygget. We can assume that there are more barriers, but that they where not presented in the interviews. There are also less barriers at Miljøbygget than at Realfagbygget. The reason for this may be linked to the difference between size and age of the buildings, as well as different users and functions.

5.5.2 Approaches

As there are barriers in regard to energy efficiency (2.5.5), there are also approaches (2.5.4), which is presented in the theory and literature. Some of the approaches towards energy efficiency is expressed through the importance of the buildings and good technology and systems to support the management and use in a optimal way (2.5.4). There are also several approaches which is not based on the building, but rather on the management and use of the buildings (2.5.5). One of these approaches is to start a preliminary and a main project - called a energy program (2.5.5). This is to assess a full overview of the different aspect both in regard to the building, but also in regard to management, operation and use (2.5.5). An other approach is to establish energy management in an organization (2.5.5). Even though energy management is not implemented, there should still be seen as important to establishing a focus in the organization and to train and improve the facilities managers, since they play a big part towards the energy efficiency and is in contact with the users on an operational level (2.5.5). An approach is to establish a link between the facilities management and the users through the operators to support a more energy efficient behavior (2.5.5). Other important approaches is life cycle costs (2.5.5) and benchmarking (2.5.3).

The facilities management at Realfagbygget has implemented several of these approaches (4.1.4). There is established a degree of energy management to monitor and measure the energy use and to find potential for improvement, while there also is objectives in regard to energy efficiency (4.1.4.3, 4.1.4.5). There is being implemented a degree of life cycle costs in regard to building budgeting to assess and find out how well the management, operation and maintenance is (4.1.4.3). This is related to a new focus in regard to benchmarking processes, which now has a high focus to assess current status in the facilities management at Realfagbygget and NTNU, while also assess how to improve, also in regard to the users (4.1.4.3). There is established a focus to further educate and improve the expertice of the management, operation and maintenance employees

(4.1.4.3). A common system called Lydia is implemented to support the different tasks within facilities management, which provide an overview of tasks and measures to be carried out (4.1.4.3). The facilities management at Realfagbygget and NTNU has establised several approaches and the interviews (4.1.4) indicate that they are dedicated to improve and develope towards a better practice and energy efficiency, and we can see that there are several approaches that is presented in the theory and literature that is established.

For Miljøbygget, we can say that the building in it self is an approach towards energy efficiency, both through the structure, the installations and systems (4.2.2.6). The facilities management is dedicated in regard to the monitoring and measurement and has a cooperation with Entro (4.2.4.3, 4.2.4.5). This indicate a degree of energy management, and also some degree of a energy project for Miljøbygget. This indication is supported by that the results are evaluatied and communicated to the tenants (4.2.4.5). The facilities management try to monitor and follow-up and the tenants, and there has also been established training of the users (4.2.2.7, 4.2.4.3). We can generally say that it is not only Miljøbygget that is energy efficiency, but also the approaches and focus carried out by the facilities management is supporting energy efficiency. The facilities management at Miljøbygget is trying their best to monitor and save energy and to find opportunities for further improvement (4.2.4.6). We can see that some of the approaches presented in the theory and literature is established and implemented.

5.6 Gap

The gap represents the difference between the expected and actual energy use for each year. This can also be described as a deviation. Both Realfagbygget (4.1.3.3) and Miljøbygget (4.2.3.3) has a gap between expected and actual energy use for each year - which can be described as varying. In this section we will start to analyze the gap for Realfagbygget and Miljøbygget, then analyze causes and solutions.

The gap between expected and actual energy use at Realfagbygget is mostly positive, by this we mean that the expected energy use is higher than the actual energy is for most of the calculated years, except for 2007 and 2010 (4.1.3.3). The highest negative gap was in 2010, where the difference between the expected and actual energy use was -2 784 763 kWh (4.1.3.3). The highest positive gap was in 2008, where the difference between the expected and actual energy use was 1 352 295 kWh (4.1.3.3). The closest positive gap was in 2006 where the difference between the expected and actual energy use was 136 140 kWh (4.1.3.3). The closest negative gap was in 2007, where the difference between the expected and actual energy use was -357 470 kWh (4.1.3.3). We can see that Realfagbygget is generally performing better than the expected energy use.

The gap between expected and actual energy use at Miljøbygget is mostly negative, where the only positive gap is in 2013 (4.2.3.3). The highest negative gap was in 2012, where the difference between the expected and actual energy use was -275 000 kWh. The highest positive gap was in 2013, where the difference between the expected and actual energy use was 212 000 kWh, which also was the closest positive gap (4.2.3.3). The closest negative gap was in 2011, where the difference between the expected and actual energy use was -229 800 kWh (4.2.3.3). We can see that Miljøbygget is generally performing poorer than the expected energy use.

5.6.1 Causes

The gap between expected and actual energy use (4.1.3.3, 4.2.3.3) is based on the methods used to calculate expected energy use at Realfagbygget (4.1.3.1, 4.1.4.4) and Miljøbygget (4.2.3.1, 4.2.4.4). The calculation methods used has both similar and different weaknesses as we analysed in section 5.2.2, and since they are based on the actual energy use from previous years there will be variations since the actual energy use varies based on several factors that impact the actual energy use as we analysed in section 5.3. We can argue that the calculation method used at Realfagbygget (4.1.3.1, 4.1.4.4) is a more fitting calculation method for expected energy use because of the use of average calculation, but at the same time it lacks temperature correction which perhaps could improve it. The two calculation methods used does not necessarily give a valid picture of the expected energy use for the specific year, nor any real idea of energy efficiency as it is based on historical figures of actual energy use, since there might be performed measures or be developments that would suggest a lower or higher actual energy use compared to the expected energy use for a specific year and since there is not performed any real adjustments for this. Energy efficiency could perhaps be better visualized with the other calculation methods. There are analysed several factors that could be causes of the gap, such as the impact factors analyed in section 5.3.2, the barriers against energy efficiency analysed in section 5.5.1, the facilities management analysed in section 5.4.1 and the building use and behavior analysed in section 5.4.2.

The facilities managers at Realfagbygget describe the gap (4.1.4.5) as a result in regard to technical installations and that the solutions not always fit and work well togehter, while there also is important to constantly monitor the building to reduce errors or find and fix them as fast as possible (4.1.5.4). The variations in outdoor temperature is also a cause in regard to them. At the same time there is increased activity because of more users at Realfagbygget, this activity is hard to manage and control since Realfagbygget always is open for use (4.1.5.4). Realfagbygget has been in use for 14 years (4.1.2.1), and it is becoming more and more necessary to make improvements and replace old installations, as these can contribute to a higher number of errors that cause Realfagbygget to use more energy (4.1.4.6). The users at Realfagbygget is not aware of a gap, and therefore do not know if it is good or bad (4.1.5.6). There are mentioned several factors related to the building which they see are the reasons (4.1.5.6), while there is also expressed that the gap can be a result of lack of communication and visibility of what they as users can do to contribute in energy efficiency (4.1.5.6).

The facilities managers at Miljøbygget expresses that it is hard to get the expected and actual energy use to correspond (4.2.4.5), which result in a gap. They describe the gap as a result of the tenants and tenant mix in combination with some of the solutions chosen for Miljøbygget (4.2.4.5). Since Miljøbygget is relatively new and only have been in use for over four years (4.2.2.1), there is also described that tuning to find the optimal operation of the building takes time and can be a challenge (4.2.4.5). Errors and variations in the building and installations may also lead to a higher energy use than expected (4.2.4.5), which can cause gaps. The outdoor temperature is also mentioned as a reason (4.2.4.5). The users at Miljøbygget mention the tuning of the building, the construction of the building and more users and tenants using the building as possible reasons for a gap (4.2.5.6).

5.6.2 Solutions

As we analysed in section 5.6.1, the causes of the gaps is related to the calculation of the expected energy use, compared to the actual energy use. A better calculation method could be a solution, where there is more focus on adjustments to fit the developments in the buildings in regard to the use of historical figures. Based on the calculation methods used, we think that it may be realistic to use historical figures to some degree, but that the historical figures need to be used as a basis for the calculation, where adjustments is needed to present more relevant expectations for the specific year. These adjustments could be based on better assessments of the status of the building, expected activity and use, expected developments and a better long term perspective through a stonger focus on the different impact factors and barriers, management and use. This could improve the calculations of expected energy use.

In regard to reduce the actual energy use that where analysed in section 5.3.3, there are several possible approaches that we analysed in section 5.5.2. A implementation of these approaches could lead to a reduced actual energy use and would support energy efficiency. A high focus to improve management, operation and maintenance is also important as we analyse in section 5.4.1, and to raise awereness through better visibility and communication. Monitoring and measurement is an important task to make sure that the buildings is as optimized as possible as we analysed in section 5.3.1. Since the building use and behavior is a challenge as we analysed in section 5.4.2, there is a need for better communication, visibility and information to raise awereness and suggest measures so the users of buildings also is included towards improved energy efficiecy. In section 5.1.2, we also suggested that requirements could be better adapted towards existing building rather than just for new buildings. Based on the methods used to calcualte the expected energy use, a reduced actual energy use would also lead to a reduced expected energy use in a long term perspective. A focus on management and use is important and energy efficiency must be integrated in their activities.

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Chapter 6

Conclusion - short and concise conclusion in regard to the research questions and thesis question

6.0 Conclusion

This master's thesis has a purpose to examine energy efficiency through management and use of existing non-domestic building with a focus on the gap between the expected and actual energy use. To do this, there has been conducted a literature study to collect and form a foundation of relevant theory and literature which present important aspects in relation to buildings, calculation methods, energy efficiency, management and use. The master's thesis was further designed as a case study of two existing non-domestic building - Realfagbygget and Miljøbygget - which was selected through a systematic selection method. There is also conducted 12 interviews of facilities managers and users of the two buildings to support the case study. The findings from the literature study and the case study with related interviews has been analysed and compared in an attempt to answer the research questions and thesis question. In this chapter we have written a short and concise conclusion in regard to the research questions and thesis question, based on the analysis in chapter 5. We have structured the chapter by first presenting the research questions and then the thesis question as sub-sections. Finally, we present further research.

6.1 Research questions

6.1.1 How is expected energy use calculated for existing non-domestic buildings?

The analysis show that there are several methods that can be used to calculate expected energy use. The methods to calculate the expected energy use has been categorized as ideal or realistic calculation methods. The ideal calculation methods is calculation methods that is based on different standards such as NS 3031:2007. These standards rely on standardized or measured input in the calculations, which often is based on ideal conditions. None of these standards is used to calculate the expected energy use for the operation and use phase at the two existing non-domestic buildings in the case study. The realistic calculation methods is based on historical actual energy use to calculate the expected energy use. At Realfagbygget, the calculation method for expected energy use is performed by calculating the average of actual energy use of the three last years without temperature correction to determine the expected energy use. At Miljøbygget, the calculation method for expected energy use is performed by calculating the actual energy use of the last year with temperature correction to determine the expected energy use. The analysis suggest that this may provide a realistic image of the expected energy use, but that there also is weaknesses with this calculation method, such as lack of adjustments in relation to potential developments. It is the facilities management that carry out the calculations of expected energy use.

6.1.2 What factors affect energy use in existing non-domestic buildings?

The analysis suggest several impact factors that affact the energy use in existing non-domestic buildings. There are impact factors that affect a building before it is completed that will lay the basis of the buildings performance. These impact factors relate to requirements and the choice of localization, design, construction, and solutions. The impact factors that affect a buildings energy use after the building is completed is linked to the management, operation, maintenance and use, aswell as the outdoor temperature. How much the different impact factors affect the energy use varies from building to building. It is clear evidence based on the case studies and interviews that these factors impact the energy use at Realfagbygget and Miljøbygget. Both of the buildings use energy monitoring devices installed at the building to gather and communicated the energy data to a BMS which is futher gathered in a EMS.

6.1.3 How does the management and use affect the energy efficiency in existing non-domestic buildings?

In the analysis there is clear indications that the management and use affect the energy use and therefore the energy efficiency. The management (the facilities management of the buildings) affect the energy use through their expertice and experience, how well the different tasks are performed, how well the building is operated and monitored, and how well the users needs and expectations are met. The energy efficiency is also affected in regard to how good the facilities management are to develope, improve and adapt to changes, and how well predicted and unpredicted challanges are solved. Users of buildings has different behaviors and patterns and therefore use the buildings differently. This means that they pose a great challenge in terms of the management of buildings, area and energy efficiency. It is also clear that the users lack of awareness in regard to energy use, saving and efficiency. The management and use also affect the energy efficiency through a lack of communication, visibility, follow-up and measures.

6.2 Thesis question

6.2.1 How to reduce a gap between expected and actual energy use in existing non-domestic buildings?

The analysis show that there are a gap between the expected and actual energy use at both Realfagbygget and Miljøbygget. The causes for this is based on how the expected energy use is calculated - the methods used at Realfagbygget and Miljøbygget. The gap is further affected by how the actual energy use develop through different impact factors that affect the actual energy use. To reduce a gap between the expected and actual energy use, both to ensure a more stable energy management, but also to ensure improved energy efficiency, depend on how well barriers against energy efficiency is broken down, how the impact factors are handled and if there is established measures and approaches to reduce the energy use. This is linked to the focus and performance of the facilities management and the communcation, information and follow-up that is directed towards the users of the building to ensure that they know how they impact the energy use and how they can contribute to reduce it. There should also be established solutions to reduce the users opportunity to affect the energy use. An example is automated demand controll of technical installations in buildings and smart buildings that can reduce the users possibility to have an impact - to some extent. Since the impact on actual energy use depend on various factors that are associated with varying uncertainties to what extent the factors will affect each specific year, it can be concluded that there always will be some degree of uncertainty to the expected and actual energy use, that will result in some degree of a gap.

6.3 Further research

There is a clear need for further research towards of how users and their behavior in different non-domestic buildings can be mapped better to enable realistic simulations that can support the calculations of the expected energy use to be more precise. Users are especially difficult to place in the calculations of energy use, which could lead to a gap between expected and actual energy use. It should be addressed further research on realistic calculation methods that can be used in existing non-domestic buildings to create a better and more realistic estimate of expected energy use, where possible impact factors and developments can be included in the calculations. Since users impact the energy use in buildings through their use and behavior in the buildings, we can see a need on research towards measures that can reduce their possibility to impact and to neutralize the it. It should also be addressed further research on how existing buildings may be affected by new technical requirements, if appropriate, and to what extent this may contribute so that new technical requirements not only are aimed at new buildings, but also for existing buildings.

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Appendix

Attachments to our master’s thesis

Appendix 1 - Interview guide for interview of users

Presentation

We are two master's students in our final year of the master's program in Real Estate and Facility Management at NTNU in Trondheim. We are now working on our master's thesis which is the last and final work in the master's program.

The purpose of the master's thesis is to investigate the energy efficiency of existing non-domestic buildings through a focus on the gap between expected and actual energy use and management and use.

As part of this, we want to interview two to three facilities managers in two different facilities management organizations, which each manages a non-domestic building. We also want to interview two to four users of each of the buildings. This result in a total of eight to 14 respondents, four to seven for each building.

All information will be treated confidentially and will only be used in this master's thesis.

Is it okey that we use a tape recorder to record this interview?

Yes: ____________________ **No:** ____________________

If yes, is it okey that we attach the transcribed interview in our master's thesis if it is appropriate?

Yes: ____________________ **No:** ____________________

1. **Profile**
   a. What position do you have and what do you generally do during a day at this building?
   b. Which education or professional knowledge do you have?
   c. How long have you been a user of this building?
   d. How and where are you primarily located in this building?
   e. How many are you in your department, company or class in this building?

   *** The purpose of these questions are to find the background, position and location of the respondent and the respondents organization in the building.**

2. **User behavior**
   a. What areas of the building are you using - can you specify?
   b. Where are you staying the most and the least in the building?
   c. Do you have any real usage patterns - and do you think about this?
   d. Do you have any thoughts on how you influence the energy use of this building?
   e. Can you, as a user, make any adjustments in relation to indoor climate? Which?
   f. What do you think about energy use at home compared to when you are using this building?
   g. How is the focus on energy use and saving in your organization?
   h. What do you think is the reasons for a gap between expected and actual energy use? Any suggestions?
   i. What do you think can be done to point attention on energy saving and behavior for a more sustainable energy use?
   j. What measures will be best to affect and reduce energy use - from a user perspective?

   * **The purpose of these questions are to find out about the respondents user behavior and how the respondent this think may impact the energy use of the building, and also any self awareness that the user may have on this topic.**

3. **Evaluation**
   a. What do you think about the building?
   b. Do you feel that the building meet your needs and expectations?
   c. What can be improved?

   * **The purpose of these questions are to find out what the user generally think about the building in regard to needs and expecations of the building.**

Final question; anything else you want to add in regard to the topic of conversation?

Appendix 2 - Interview guide for interview of facility managers (also: operators and/or personnel)

Presentation
We are two master's students in our final year of the master's program in Real Estate and Facility Management at NTNU in Trondheim. We are now working on our master's thesis which is the last and final work in the master's program.

The purpose of the master's thesis is to investigate the energy efficiency of existing non-domestic buildings through a focus on the gap between expected and actual energy use and management and use.

As part of this, we want to interview two to three facilities managers in two different facilities management organizations, which each manages a non-domestic building. We also want to interview two to four users of each of the buildings. This result in a total of eight to 14 respondents, four to seven for each building.

All information will be treated confidentially and will only be used in this master's thesis.

Is it okey that we use a tape recorder to record this interview?

Yes: ____________________ **No:** ____________________

If yes, is it okey that we attach the transcribed interview in our master's thesis if it is appropriate?

Yes: ____________________ **No:** ____________________

1. **Profile**
   a. What position do you have and what do you generally do during a day in regard to this building?
   b. Which education or professional knowledge do you have?
   c. How long have you been a facility manager of this building?
   (Or; how long have you been working with the building?
   d. How long have you had your current position?
   e. How many years have you been in this discipline area?

   *** The purpose of these questions are to find the background and position of the respondent and the respondents relationship towards the building.**

2. **Organization**
   a. Which organization has the responsibility to manage this building?
   b. How is the organizational structure?
   c. How is the operation and management organized in general and how is it organized in regard to this building?

   * **The purpose of these questions are to find out about how the facility management organization is organized and how operation and management is organized both in general and towards the building discussed.**

3. **Management and tasks**
   a. What responsibilities and duties do you have?
   b. Can you describe a general workday for you?
   c. What is your's and your organization's vision and goals in regard to management of buildings and how do you achieve this?
   d. How was the building originally intended to be managed, maintained and used? Is it like this today?
   e. Is the building managed in regard to best practice? What are you thoughts on this topic?

   * **The purpose of these questions are to find out about the repondants responsibilites and tasks, as well as the respondends and the respondent's organi zations vision and goals towards management of buildings. We also want to know how if the building is managed as it should and if this is done towards best practice.**

3. **Calculation of energy use**
   a. Do you make any energy use budgets for management and use? If so, how is this done? If not, how do you calculate or predict how much energy that will be used in the building?

b. Which indicators or parameters do you use when you do energy calculations?
c. What models or methods is used to make the calculations?
d. Who calculated the expected energy use of this building before it was constructed and do you know when was this done (in which phase was this done)?
e. Who calculate the expected energy use for each year?

* **The purpose of these questions are to find out about the how and if the energy use is being calucalted, how this is done and how they predict how the energy use will be in the future for the building.**

4. Measurement of energy use

a. How is energy use and performance measured in the building?
b. How is the building monitored and which systems are included in this process?
c. How is the results between the expected and actual energy use throughout the buildings lifecycle until today? Has it been a positive or a negative development?
d. How would you explain the results?
e. What do you think is the reasons for a gap between expected and actual energy use?

* **The purpose of these questions are to find out about the how and if the energy use is being monitored and measured, how the results are looking and what the respondent think about the results, i.e. what are affecting the results.**

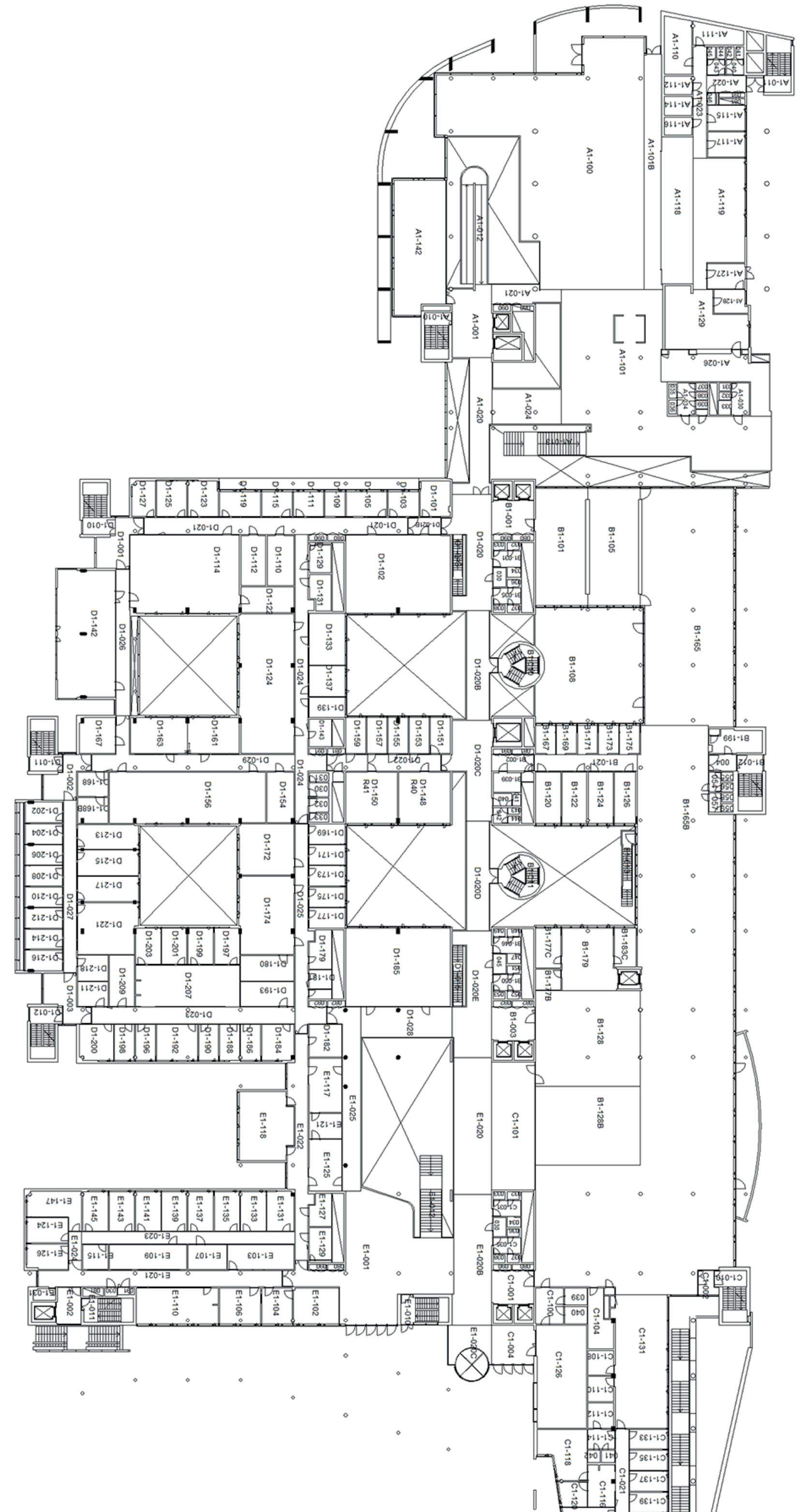
5. Evaluation

a. How would you evaluate the building from a facility management prespective?
b. How would you evaluate the building's management and operation?
c. How could the building be managed and operated better?
d. Do you have any imput on how management could reduce energy use in this building?
e. Have there been any challenges in regard to this building?

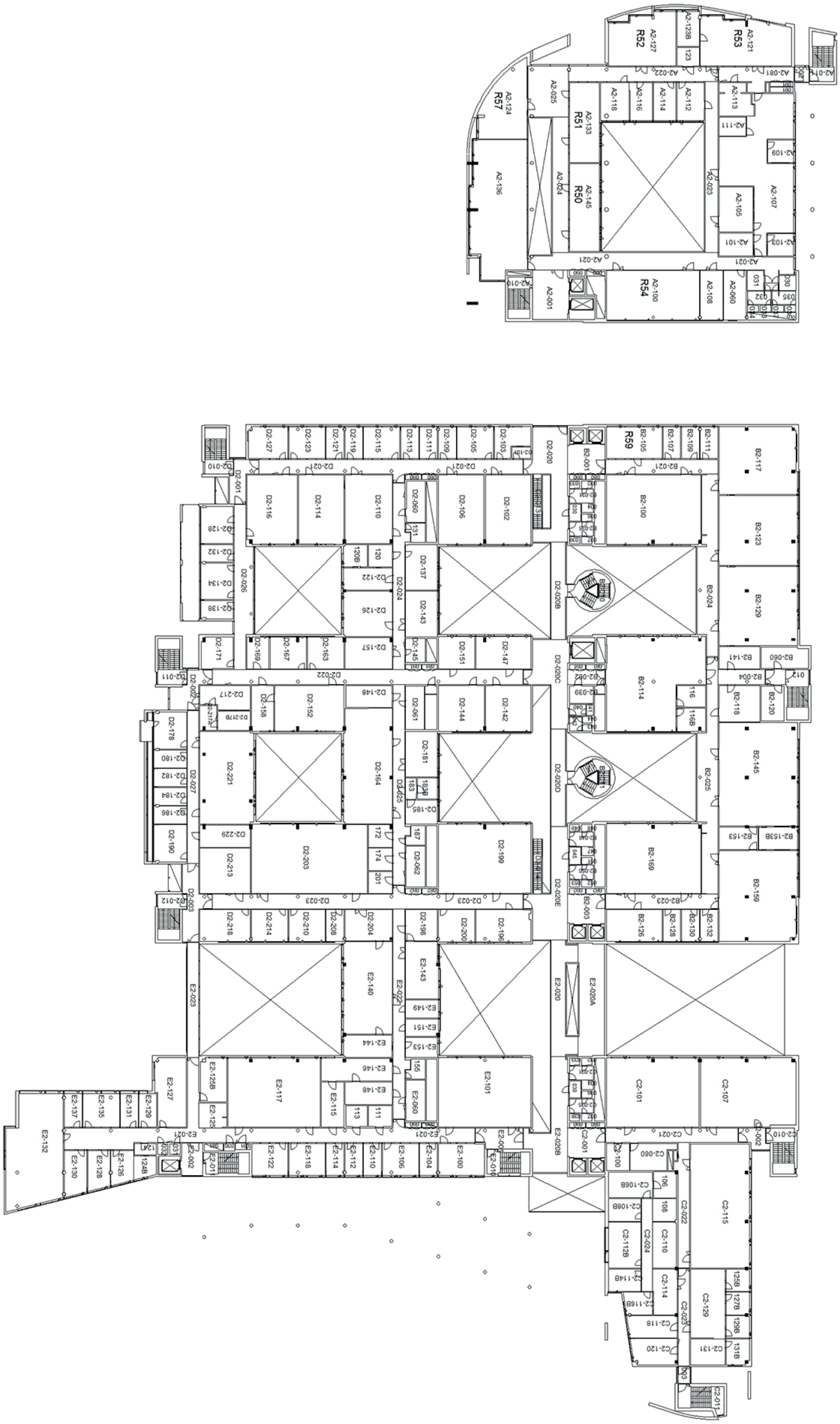
* **The purpose of these questions are to find out about how the respondent evaluate the building, the building's management and operation, how it could be managed better and what the respondent think about energy use optimization in regard to management.**

Final question; anything else you want to add in regard to the topic of conversation?

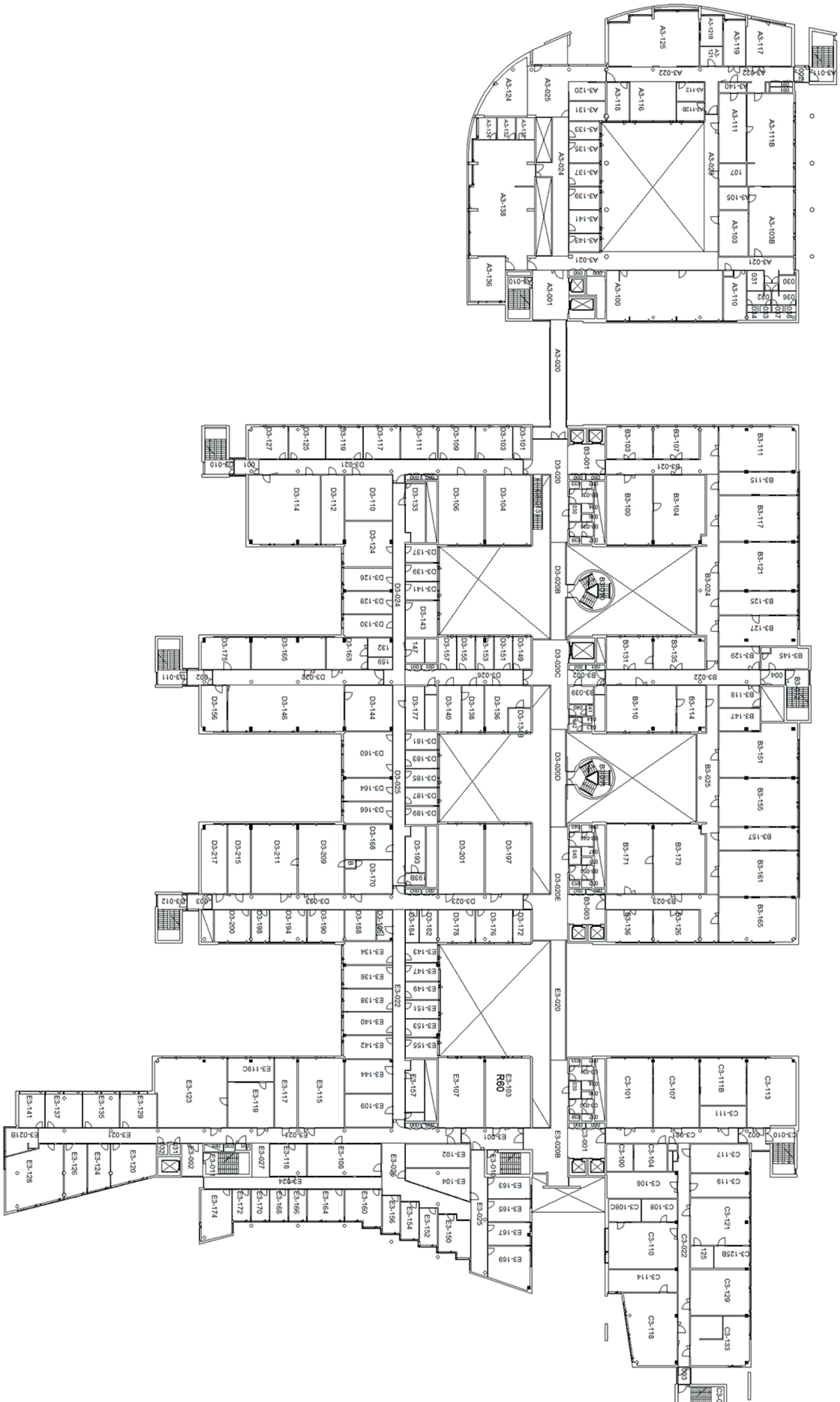
Appendix 3 - Floor plan of the first floor at Realfagbygget (NTNU 2014a)



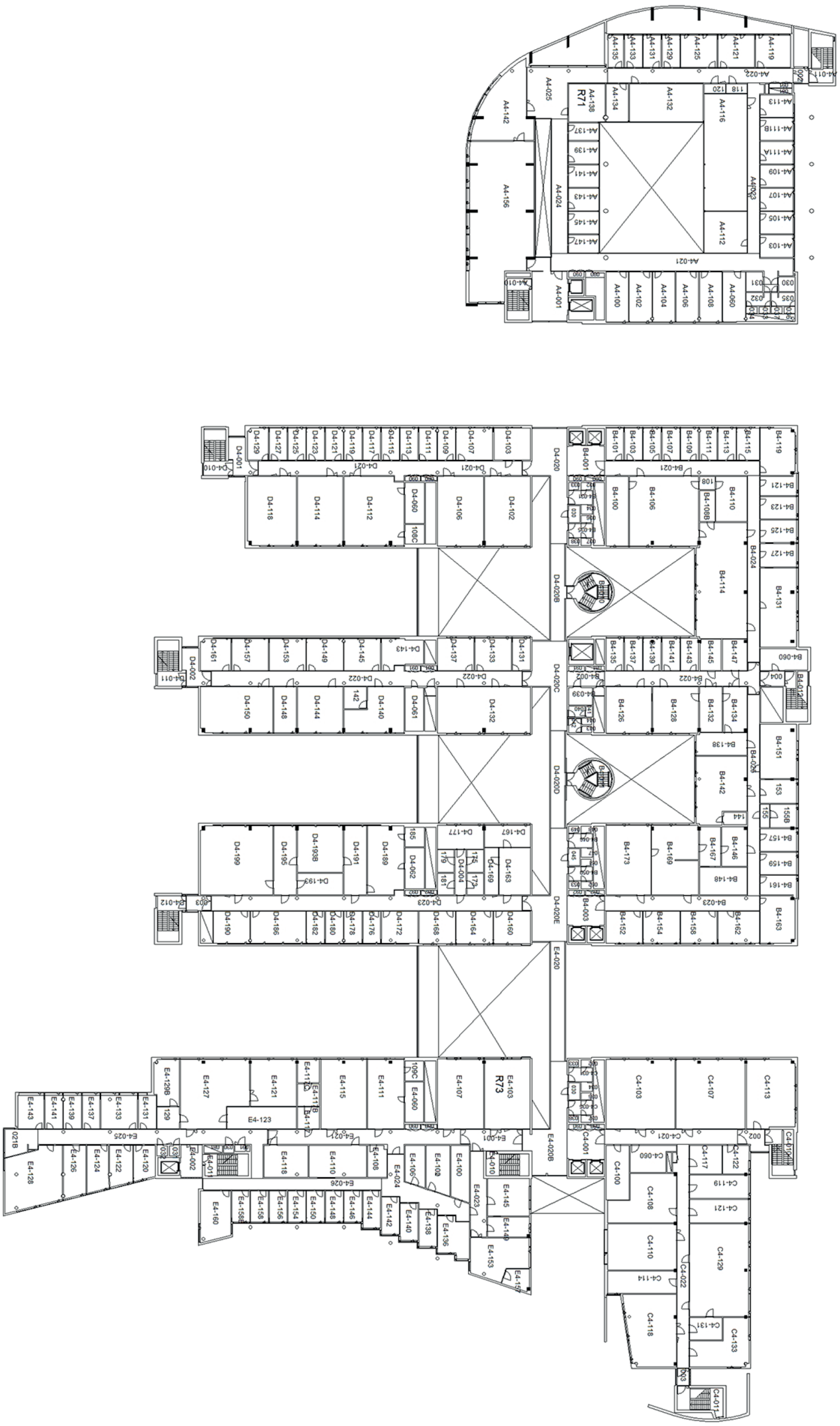
Appendix 4 - Floor plan of the second floor at Realfagbygget (NTNU 2014e)



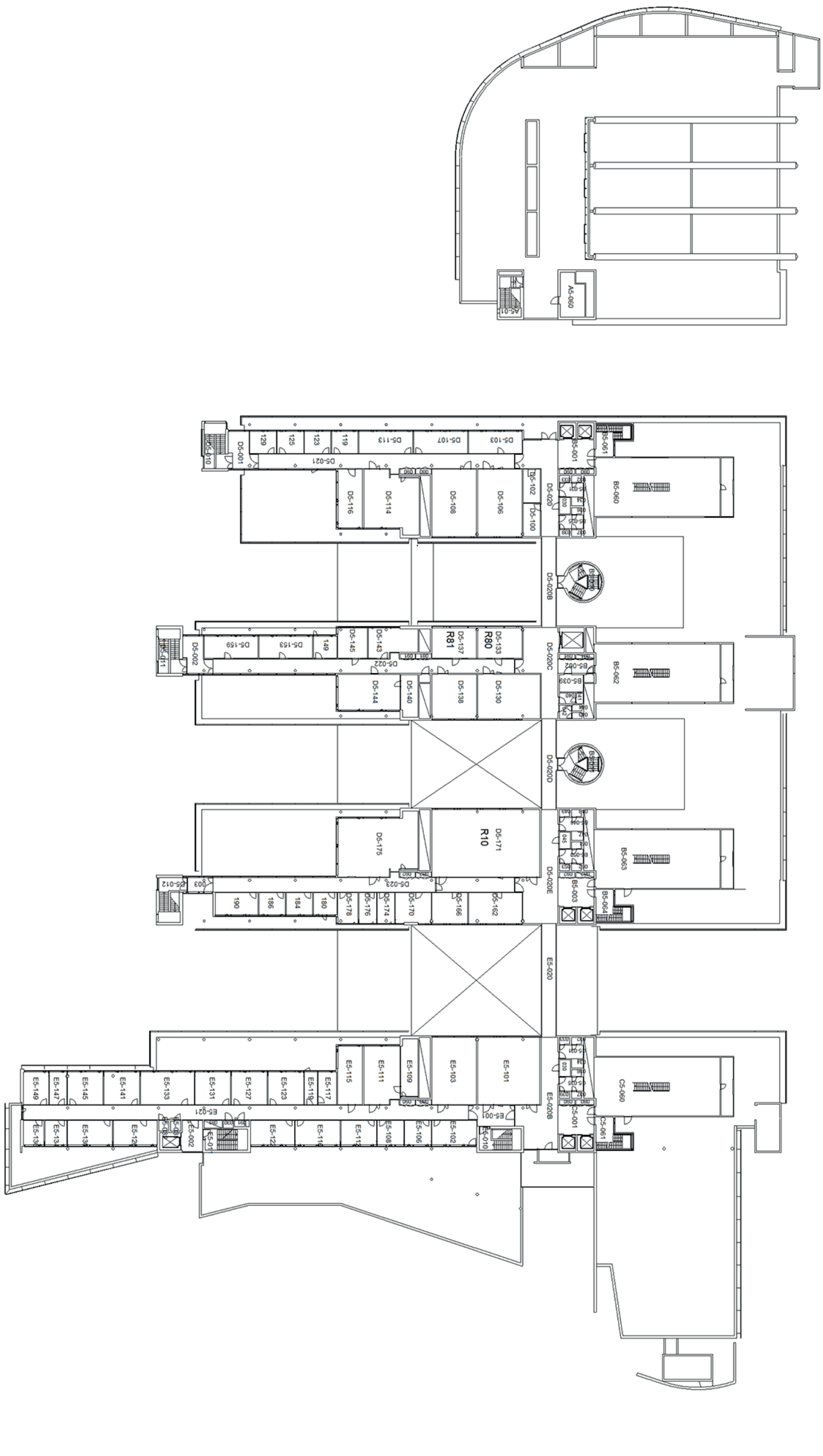
Appendix 5 - Floor plan of the third floor at Realfagbygget (NTNU 2014f)



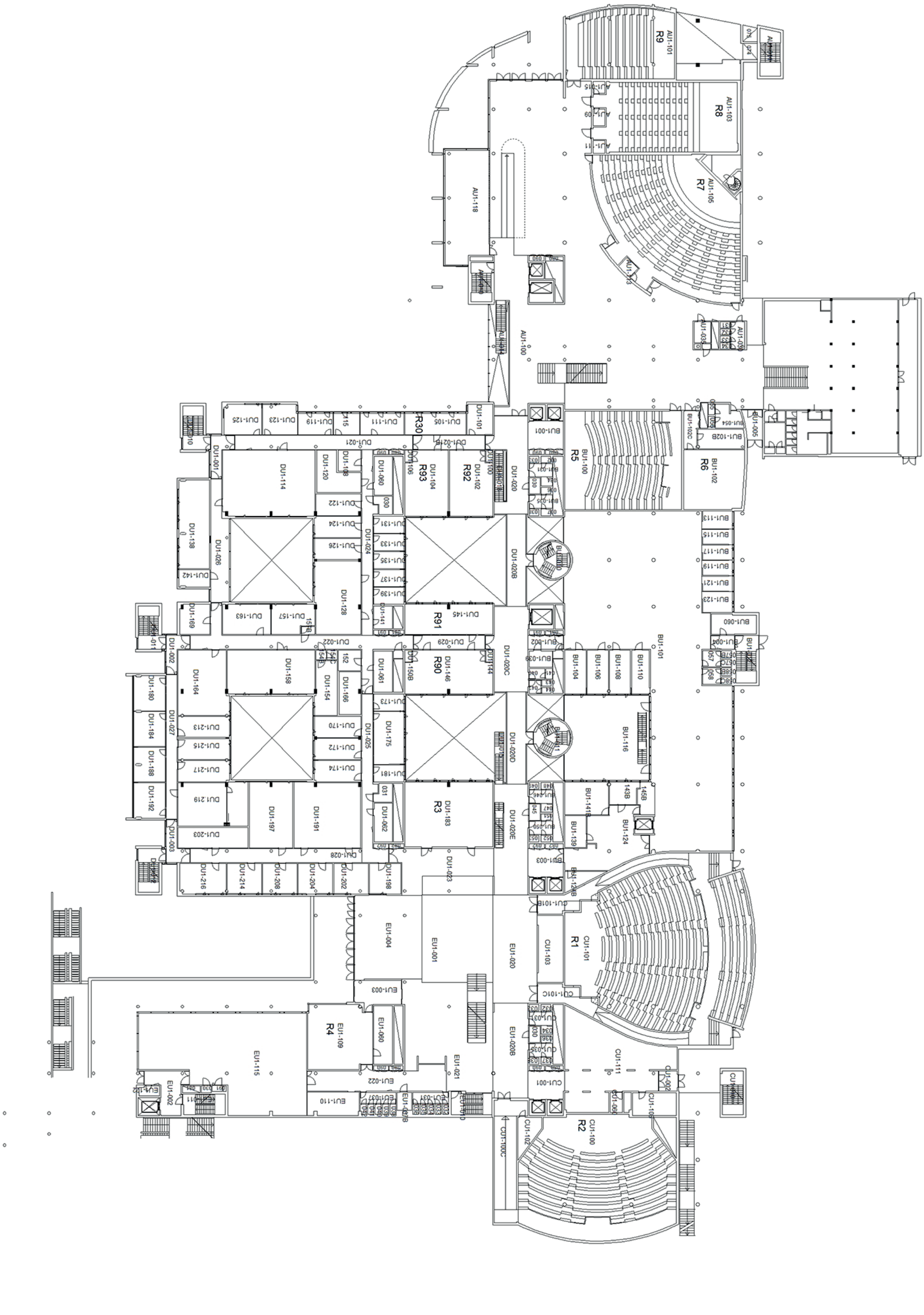
Appendix 6 - Floor plan of the forth floor at Realfagbygget (NTNU 2014g)



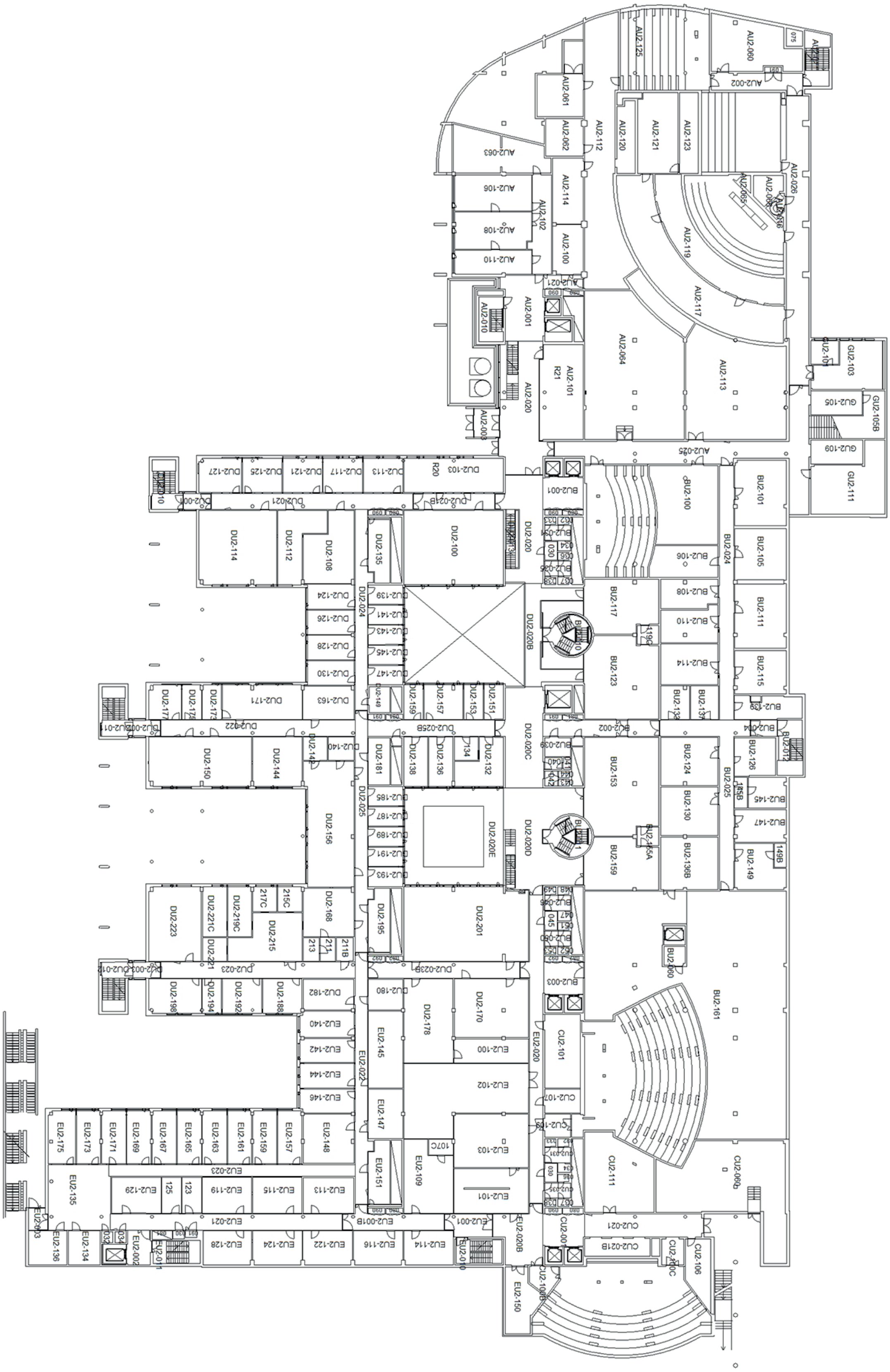
Appendix 7 - Floor plan of the fifth floor at Realfagbygget (NTNU 2014h)



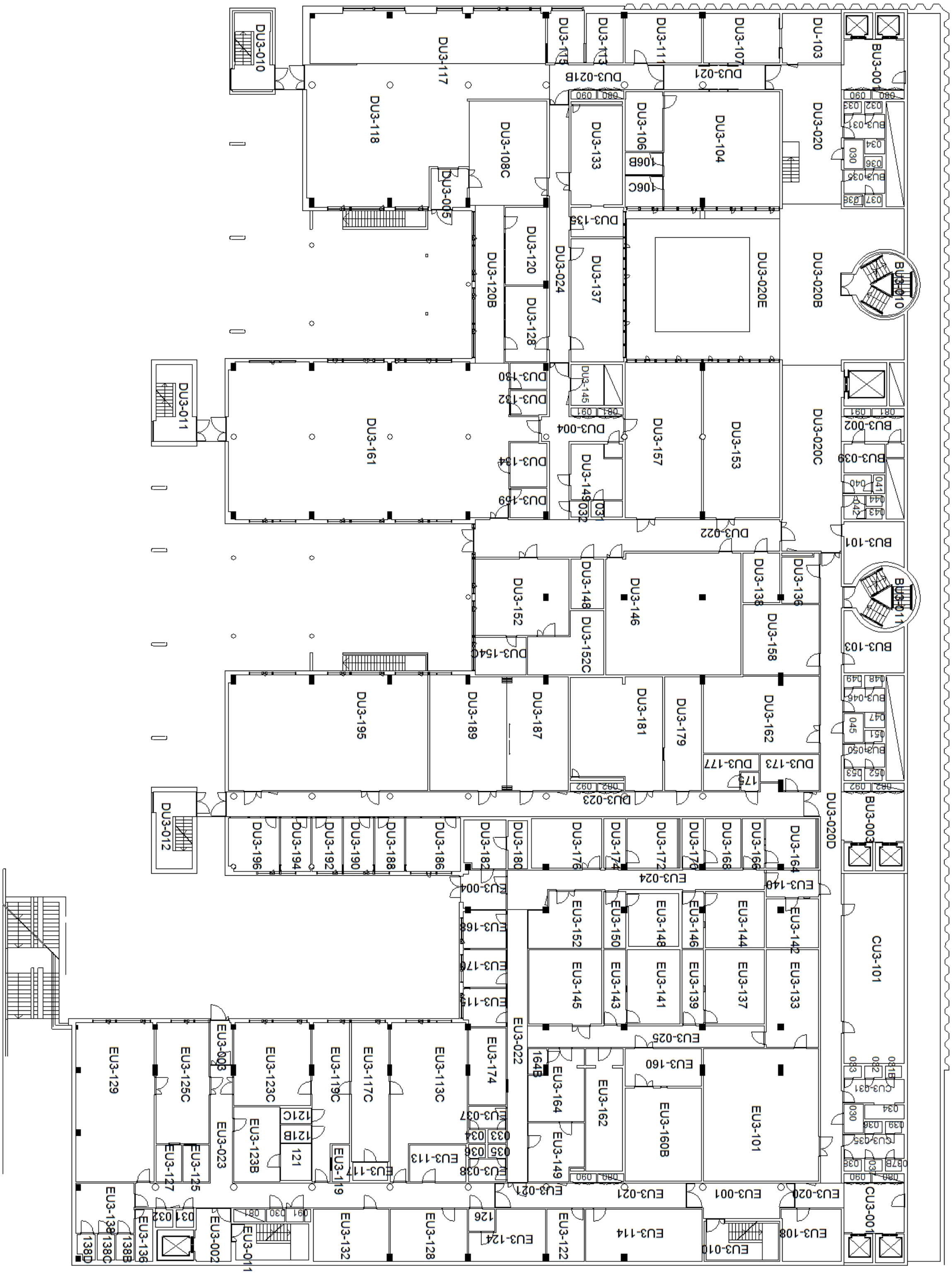
Appendix 8 - Floor plan of the first basement floor at Realfag-bygget (NTNU 2014i)



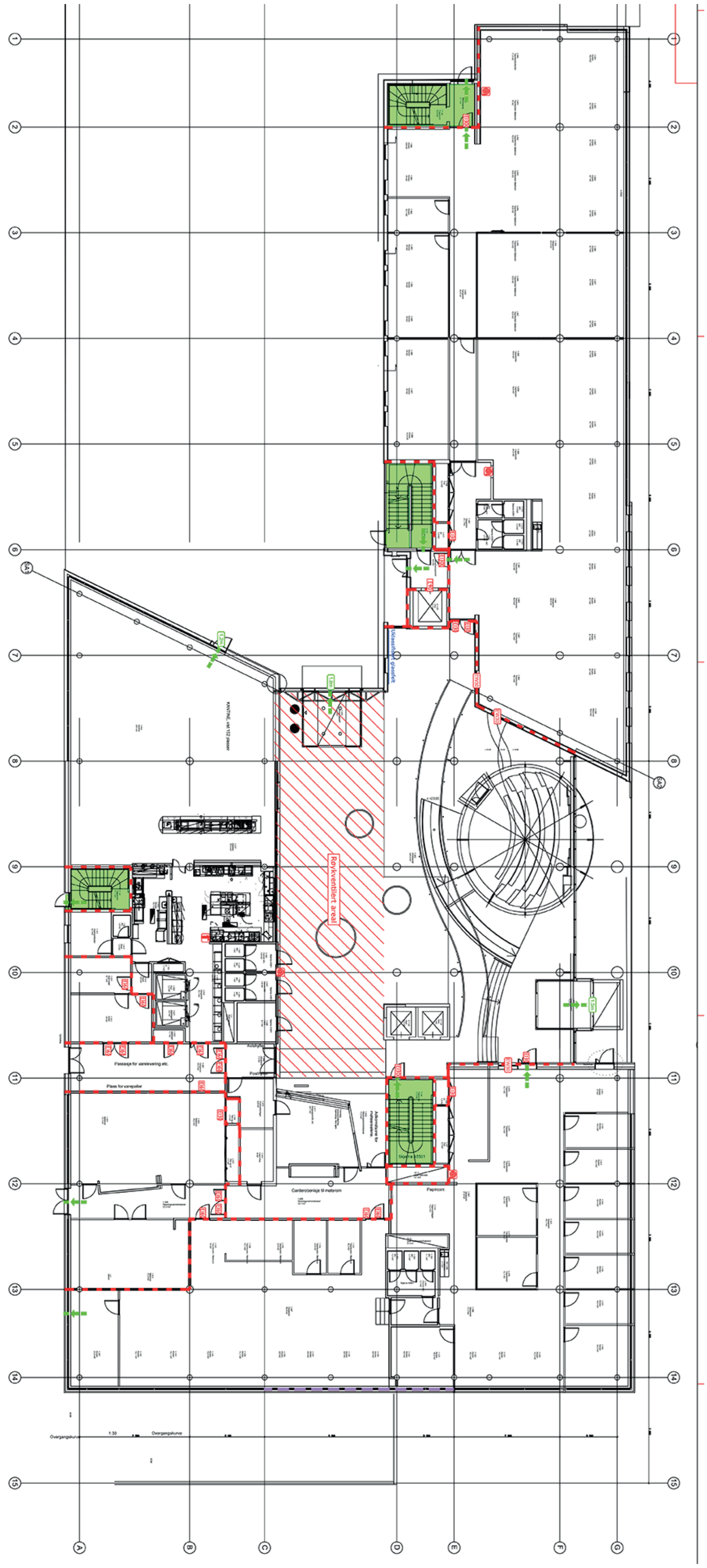
Appendix 9 - Floor plan of the second basement floor at Realfagbygget (NTNU 2014j)



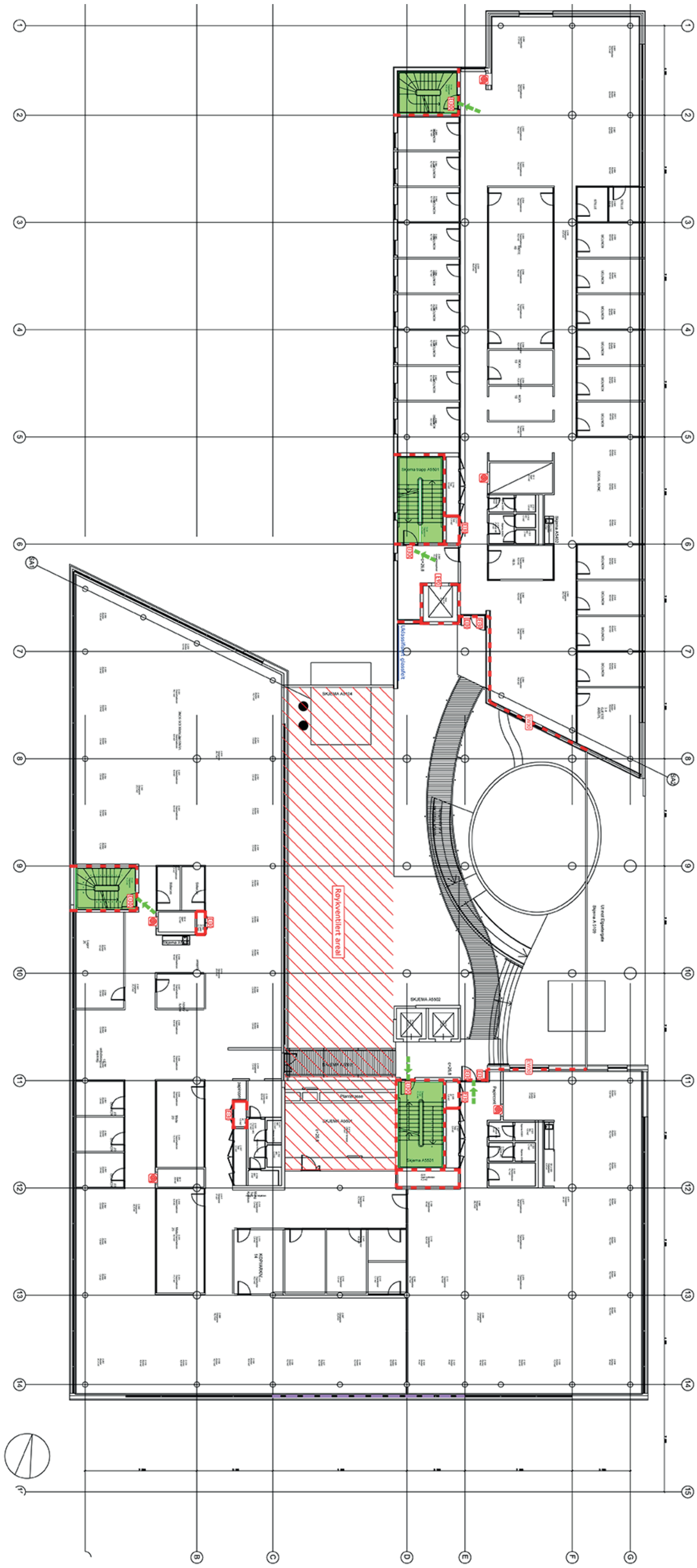
Appendix 10 - Floor plan of the third basement floor at Realfag-bygget (NTNU 2014k)



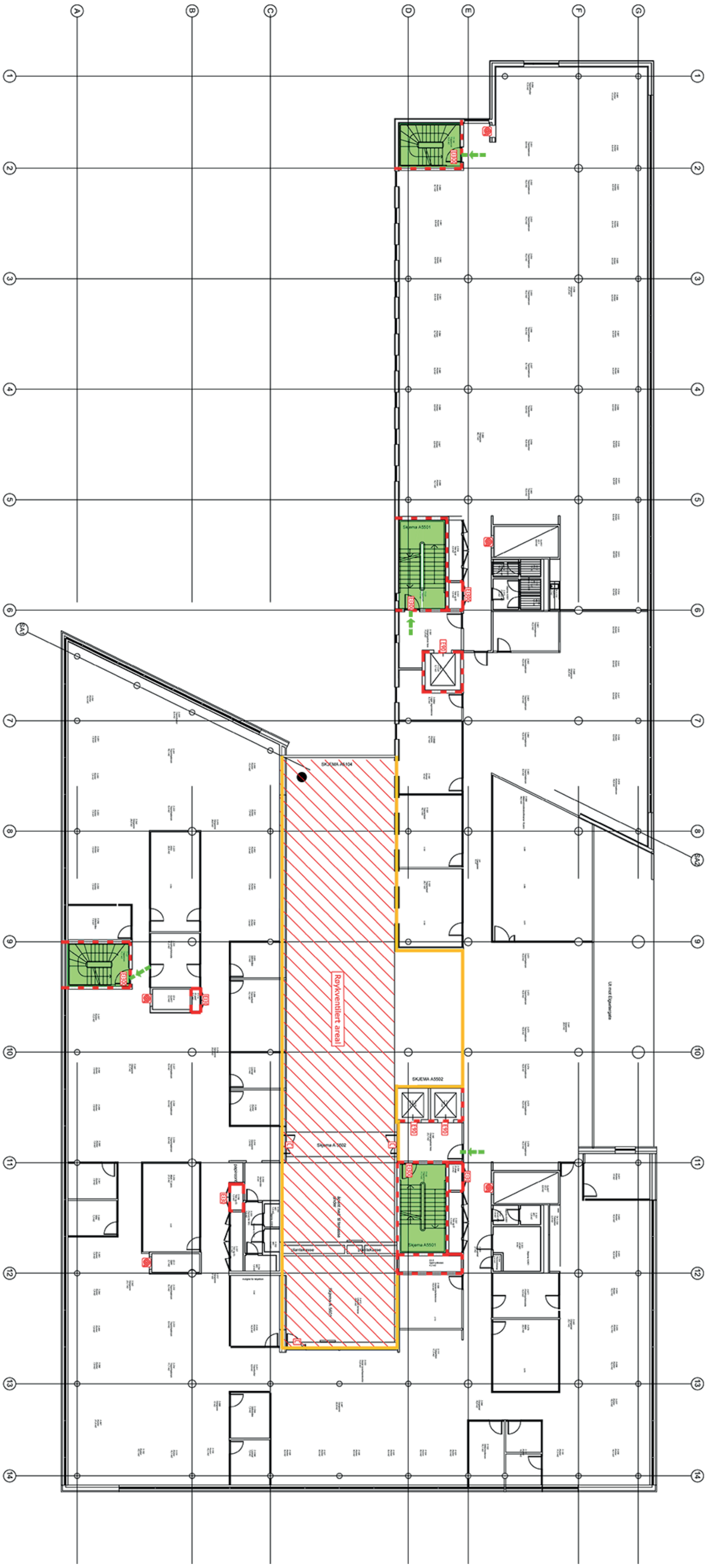
Appendix 11 - Floor plan of the first floor at Miljøbygget (received from a respondent)



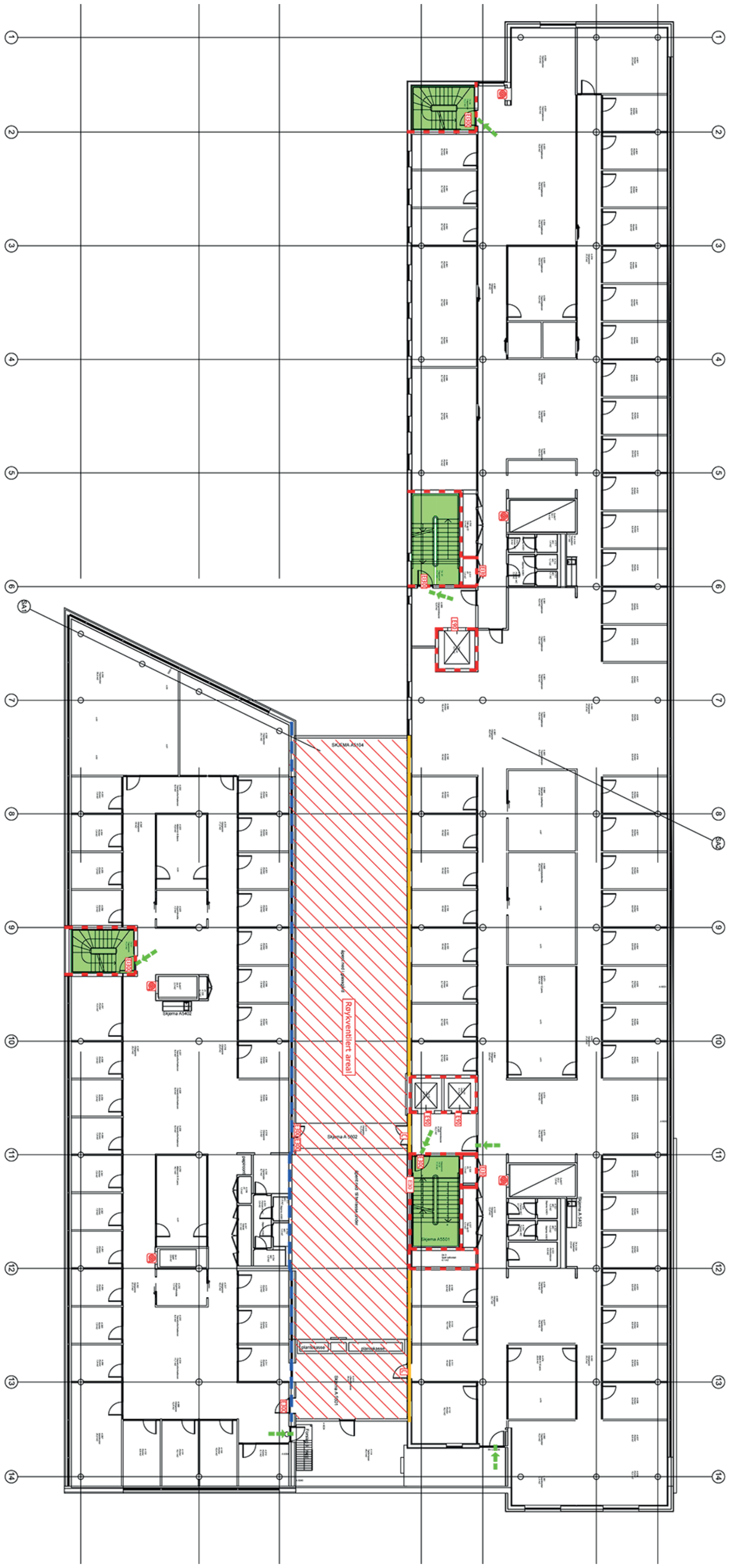
Appendix 12 - Floor plan of the second floor at Miljøbygget (received from a respondent)



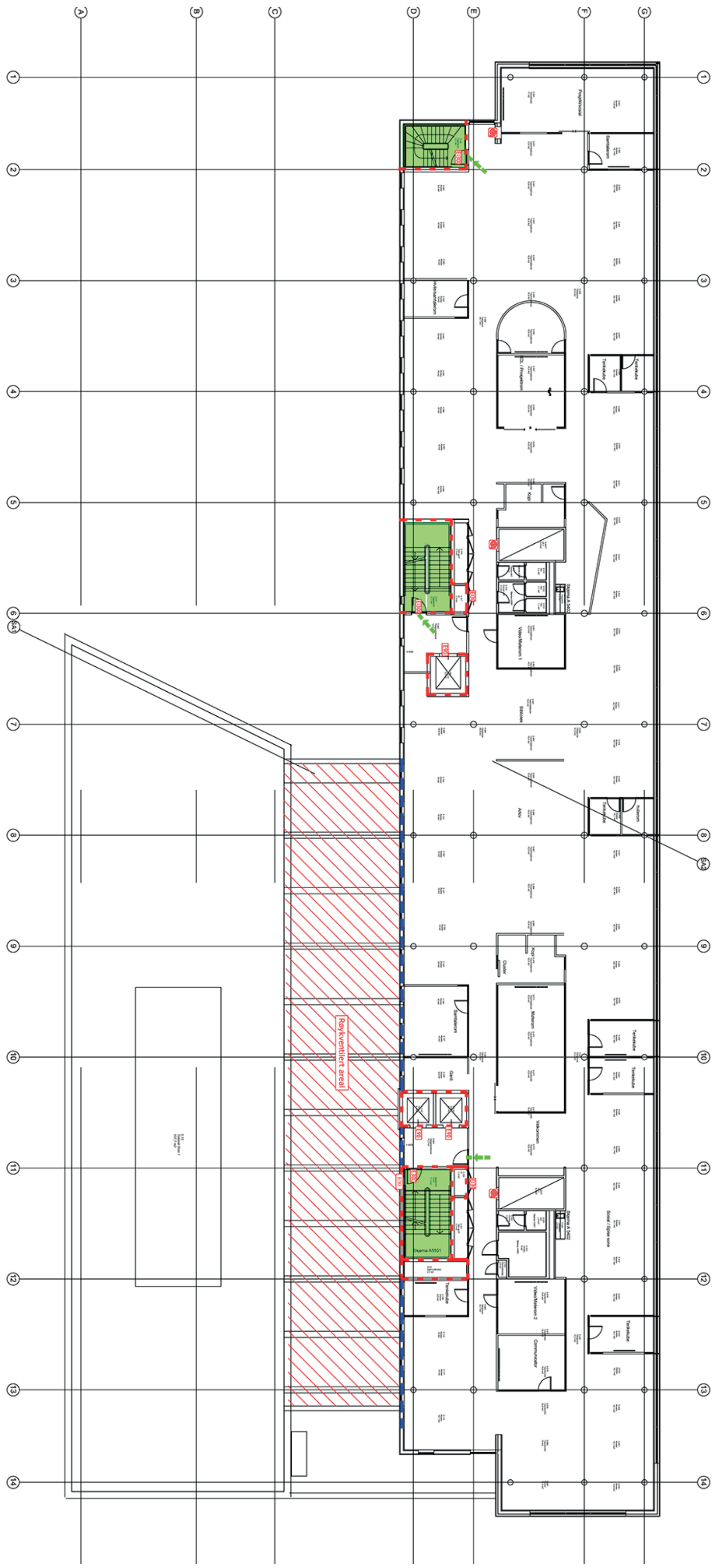
Appendix 13 - Floor plan of the third floor at Miljøbygget (received from a respondent)



Appendix 14 - Floor plan of the forth floor at Miljøbygget (received from a respondent)



Appendix 15 - Floor plan of the fifth floor at Miljøbygget (recei-ved from a respondent)



Appendix 16 - Floor plan of the sixth floor at Miljøbygget (recei-
ved from a respondent)

Appendix 17 - Floor plan of the basement floor at Miljøbygget (received from a respondent)

Appendix 18 - Energy use at Realfagbygget (based on figures received from a respondent)

Actual electricity use												
Month	**2014 [kWh]**	**2013 [kWh]**	**2012 [kWh]**	**2011 [kWh]**	**2010 [kWh]**	**2009 [kWh]**	**2008 [kWh]**	**2007 [kWh]**	**2006 [kWh]**	**2005 [kWh]**	**2004 [kWh]**	**2003 [kWh]**
January		904014	966565	939260	921405	932045	943915	995185	937690	900740	918915	892675
February		863664	904267	908360	852775	861105	902870	902935	895975	859610	897015	850610
March		907455	978051	1012120	945925	931840	902805	956180	1000695	919260	952495	917410
April		961603	932447	1068170	979770	854420	913645	870385	872125	908440	870330	847995
May		1023838	999293	1043149	1030405	917175	934235	939335	962940	933195	900570	943125
June		943780	986260	866822	989655	878445	868295	922400	926465	900420	854975	891875
July		903665	959128	915492	971800	919990	839950	842160	913845	921120	773785	922765
August		974082	1015501	992619	1051245	987500	835555	882600	1014785	880430	940230	883325
September		992406	1011287	1022580	1071115	1008145	894605	875645	947340	899765	930220	867050
October		1037826	1022106	1038651	1057860	1045495	964115	938710	963915	919120	915780	890295
November		1033134	952399	1033819	962650	1012400	955740	927605	944220	932675	944070	886560
December		960362	887915	1042083	908450	1014925	914490	889680	896660	924065	903690	844985
Total		11505829	11615219	11883125	11743055	11363485	10870220	10942820	11276655	10898840	10802075	10638670

Actual district heating use												
Month	**2014 [kWh]**	**2013 [kWh]**	**2012 [kWh]**	**2011 [kWh]**	**2010 [kWh]**	**2009 [kWh]**	**2008 [kWh]**	**2007 [kWh]**	**2006 [kWh]**	**2005 [kWh]**	**2004 [kWh]**	**2003 [kWh]**
January		976864	988096	824854	1288980	708500	872620	937460	800380	739160	1178100	1179280
February		794888	756137	821849	1098580	772140	761600	1054800	758180	839460	856680	898120
March		836192	457760	634700	800460	411060	758640	558180	1021300	791380	651040	715860
April		367496	483208	206669	416480	253240	359860	437120	404780	372760	326480	472620
May		58608	204737	67248	242560	106060	162940	264320	233880	280220	216960	328860
June		5224	54893	17808	88060	75220	56040	118240	166220	185800	133280	145680
July		1096	32	9696	20820	19520	4450	82480	86700	98580	99600	68240
August		1560	32	7208	33280	25300	13720	138840	61340	308340	73320	112500
September		39792	88888	29136	185160	127240	76640	273120	167640	230580	197980	238980
October		262768	367216	244072	438360	516822	242620	426640	409640	388440	409880	519540
November		531656	506056	348560	1102700	593260	452060	780780	577560	544800	798200	682880
December		668448	1126328	790872	1394520	993320	692600	900780	552220	918480	817400	798840
Total		4544592	5033383	4002672	7109960	4601682	4453790	5972760	5239840	5698000	5758920	6161400

Appendix 19 - Energy use at Miljøbygget (based on figures received from Entro)

Actual total energy use				
Month	**2014 [kWh]**	**2013 [kWh]**	**2012 [kWh]**	**2011 [kWh]**
January	168 000	209 000	220 000	194 000
February	112 000	181 000	190 000	157 000
March	138 000	177 000	170 000	150 000
April		134 000	135 000	101 000
May		120 000	124 000	105 000
June		119 000	119 000	99 000
July		104 000	115 000	96 000
August		126 000	129 000	102 000
September		128 000	129 000	120 000
October		101 000	155 000	134 000
November		126 000	175 000	151 000
December		129 000	205 000	182 000
Total	418 000	1 654 000	1 866 000	1 591 000

Actual domestic heating use				
Year	**2014 [kWh]**	**2013 [kWh]**	**2012 [kWh]**	**2011 [kWh]**
Total	207 554	428 658	481 246	425 770