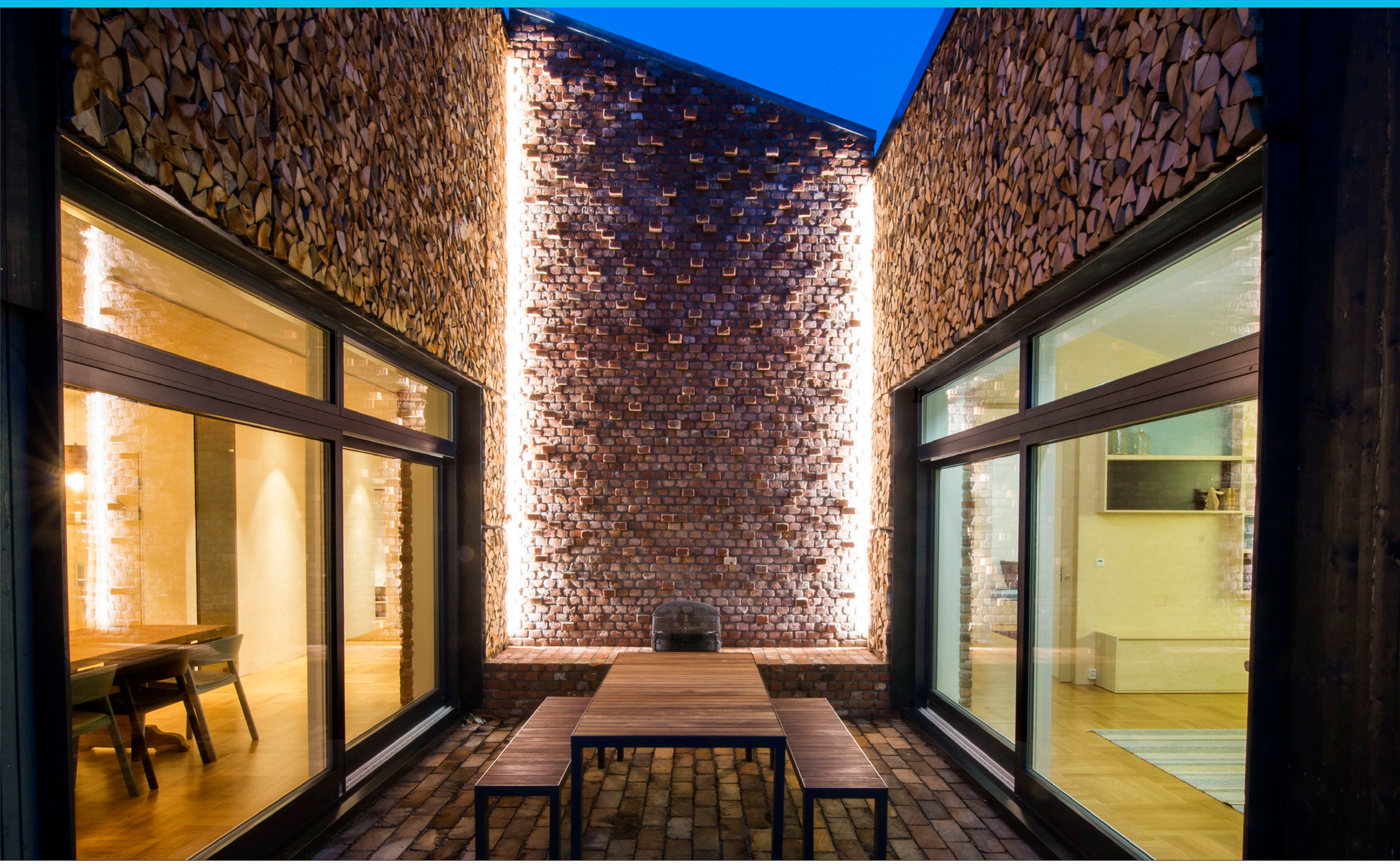
ZEB Project report 30 – 2017

Anita Moum, Åshild Lappegard Hauge and Judith Thomsen

Four Norwegian Zero Emission Pilot Buildings – Building Process and User Evaluation

The Research Centre on Zero Emission Buildings



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Abstract

About ZEB

The Research Centre on Zero Emission Buildings (ZEB), Norway (www.zeb.no), funds the research work presented in this report. ZEB is a national centre dedicated to research, innovation, and implementation within the field of energy efficient zero emission buildings. The Research Council of Norway assigned The Faculty of Architecture and Fine Art at NTNU to host one of eight new national centers for Environment-friendly Energy Research (FME). The duration of ZEB is from 2008-2016. The main objective of ZEB is to develop competitive products and solutions for existing and new buildings that will promote market penetration of buildings with zero greenhouse gas emissions in connection with their production, operation, and demolition. The Centre's research encompasses residential, commercial, and public buildings.

ZEB focuses on five areas that interact and influence each other:
1: Advanced materials technologies
2: Climate-adapted, low-energy envelope technologies
3: Energy supply systems and services
4: Use, operation, and implementation
5: Concepts and strategies

This report is a part of area 4: Use, operation, and implementation.

Objective

The objectives are to 1) identify and analyze characteristics of processes leading towards zero emission buildings through studying experiences, drivers and barriers encountered in pilot projects, 2) identify and analyze aspects influencing use of zero emission buildings; and 3) make recommendations on how to plan a successful process towards a zero emission building project with high quality.

Method

The results are based on qualitative interviews in 4 case studies of zero emission pilot buildings. The building process and early use phase (where relevant) of each pilot building is studied through individual or group interviews of 5-8 persons per case study. The persons interviewed were clients, building owners, architects, consultants or contractors.

Findings and recommendations

Characteristics of successful processes leading towards zero emission pilot buildings are:

- To regard the way from high ambitions into good buildings as a development project of its own, requiring careful planning, management and follow-up.
- To formulate clear goals, connected to an understanding of purpose and legitimacy. The clients, the executing parties and the building owners and users must be committed to the goals.
- To motivate all parties for "mastering the unknown".
- To focus strongly on collaboration and involvement, in procurement forms and contracts, through management style and trough the establishment of good meeting arenas. It is important to involve production actors[1] early in the development process.

[1] Builders, producers, site workers and others.

- To make available extra resources for the project, such as money and time. Zero emission buildings are per 2016 innovation projects, which require more resources than traditional building projects.
- To utilize support and competence of experts (consultants or researchers) and enthusiasts to gain sufficient competence and increase personal engagement among the project parties.
- To follow up the commitment and the ZEB-goals after handover.

In addition, the pilot cases revealed the importance of the hand-over phase, and how to make this phase easier, and thereby increase the chances of succeeding with the building. These advices are important in all building processes, but especially important not to lose sight of in zero emission projects:

- To work for continuity in project ownership. For instance through public-private partnership-models or other formal means for committing the clients and/or executing parties in the operation and facilities management of the building.
- To involve the users (and the FM-staff) at an early stage development. Mapping actual needs and challenges.
- To create ownership and understanding of the consequences, benefits and challenges given by the zero emission concept among the users. This will prepare for higher user acceptance of challenges in the running-in phase after handover.
- To commit central actors in design and construction to follow up with improvements and evaluations in the early use phase.

Further research
We would recommend continuing with evaluations of zero emission buildings for detecting a more detailed picture of the challenges and opportunities. More research is needed on how to "cross the chasm" between ZEB as pilot projects for the early adapters and ZEB as established practice for the majority in the Norwegian construction industry. Further, there is a need for a wider perspective on the building in a smart city context, and a need for focusing on how the societal context influences the users' evaluation of the building.

Contents

1. Introduction

1.1 Background

Europe sets ambitious goals when it comes to energy and climate change mitigation, with objectives to reduce greenhouse gas emissions, increase the share of renewable energy and increase energy efficiency by 20 % within 2020. In order to realize these targets, the EU has put forward an energy efficiency plan with specific measures to save more energy (EU, 2010).[2] Reflecting these ambitions, regulations and legislation are now tuned for nearly zero energy use. In Norway, the importance of increasing energy efficiency in buildings was addressed in the first Norwegian White Paper on buildings (St.meld. nr. 28, 2011-2012), launched in 2012. The White Paper has notified a two-step revision process of the existing building regulations, to passive house level in 2015 and near zero level in 2020.

The building process of zero emission buildings and the way the actors organize, manage and carry out their tasks, can be expected to differ from traditional building processes. What characterizes a process towards a successful zero emission building? How do the users experience living or working in a zero emission building?

1.2 Aims

This report presents the results of a qualitative evaluation of four pilot building projects in the *Research Centre on Zero Emission Buildings* (ZEB). The aim of the evaluation is to:

1. Identify and analyze characteristics of processes leading towards zero emission buildings through studying experiences, drivers and barriers.
2. In the relevant case studies, identify and analyze aspects influencing use of zero emission buildings.
3. Based on the results, give recommendations on how to plan a successful process towards a zero emission building project with high quality.

1.3 Scope and limitations

The research work of the ZEB Centre is organized in work packages with different perspectives and scopes. This report and the related evaluations are part of the work package called "Use, operation and implementation of zero emission buildings", which focuses on:

> *(...) how zero emission buildings perform in real life conditions that are characterized by a high number of non-technical influences. End-users exhibit unexpected behaviors, building operators act on a tight time budget, and economic considerations influence which solutions are selected when the building is built. The research conducted here aims at describing societal, cultural and political patterns that can be used to deliver zero emission buildings that work at least as well as expected when they are used, operated and implemented by real human beings.*[3]

[2] Plans and strategies are stated in various policy documents on EU level (by the 2020 climate & energy package, by the Energy Efficiency Directive, by the Energy Performance of Buildings Directive.

[3] Stated on the home-page of ZEB (November 2016): http://zeb.no/index.php/en/use-operation-and-implementation-of-zero-emission-buildings.

The evaluations discussed in this report are limited to non-technical aspects related to the:

- Building process; particularly design, procurement and construction (in all four pilot projects)
- Handover and early use phase (in two of the pilot projects)

Each of the four pilot building projects have defined their own level of ambition according to the ZEB center ambition level definition (Fig. 1). Not all ZEB pilot projects have been completed and/or yet taken over by users by the end of this research work and the ZEB Centre. Therefore, the take-over and early use phase could be studied and discussed in only two of the four pilot projects.

Zero Emission Buildings Definitions

A zero emission building produces enough renewable energy to compensate for the building's greenhouse gas emissions over its life span. The Norwegian ZEB research center has defined different levels of zero emission buildings depending on how many phases of a building's lifespan that are counted in. The main ambition levels applied by the ZEB research center are described as follows:

ZEB-O÷EQ: Emissions related to all energy use in operation "O" except energy use for equipment/appliances (EQ) shall be compensated with on-site renewable energy generation.

ZEB-O: Emissions related to all operational energy use "O" shall be compensated for with on-site renewable energy generation.

ZEB-OM: Emissions related to all operational energy use "O" and embodied emissions from materials "M" shall be compensated for with on-site renewable energy generation.

ZEB-COM: Emissions related to construction "C", all operational energy use "O" and embodied emissions from materials "M" shall be compensated for with on-site renewable energy generation.

ZEB-COME: Emissions related to construction "C", all operational energy use "O", embodied emissions from materials "M" and the end of life "E" shall be compensated for with on-site renewable energy generation.

*Figure 1. ZEB ambition level definitions (*Fufa et al, 2016*)*

The evaluations are to a based on expert interviews (Bogner et al, 2009) with key actors involved in the building process and early use phase, such as the clients, architects, consultants, contractors and, not at least, the users. The authors of this report represent different disciplines and expertise. We have viewed the results of the evaluations from various perspectives, practices and theories, such as; process-related and organizational theories, environmental psychology, social sciences, project management and architectural practice.

Other research groups in ZEB are looking more specifically at the technical performance of the ZEB pilot buildings. Their studies are, among others, based on quantitative data from observations and measurements. The results from the technical evaluations can be found in separate ZEB reports and publications. Interested readers can download them from the official homepage (www.ZEB.no).

2. Frame of reference

In this chapter, we present relevant theories, best practises and research frameworks on 1) Building processes, procurement forms and project organizations and 2) Experiences from early use phase. The first part is relevant for the research questions on success criteria for planning and building zero emission buildings, whereas the second part is relevant for the research questions on aspects influencing use and management of zero emission buildings.

2.1 Building processes, procurement forms and project organisations

The building process

The "building process" is a complex system of both sequential and highly iterative tasks and actions. Eikeland (2001) categorizes the various actions into three main groups; 1) The core processes, 2) The management processes and 3) The public processes.

Core processes

Core processes result in descriptions or production of the planned building project. Eikeland (1998) describes three main core processes (Fig 2). Firstly, the programming process, where the needs and requirements are identified and formulated. Secondly, the design process, where the physical attributes of the building are designed and described (by drawings, models, texts and more). Such descriptions serve either as basis for decisions or as instructions for construction. Thirdly, the production process, where the building is constructed.

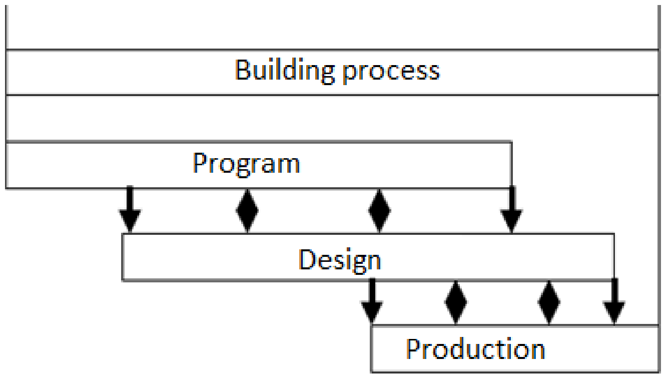

Figure 2. The core processes (Eikeland, 2001).

Figure 2 is a simplified example of a process model, illustrating some main phases with defined actions, and relations between them. There are almost as many versions of (core) process models, as there are companies. Larger clients and construction companies are using their own tailor made models, with different levels of detail and amount of stages. The teaching institutions are using their versions, such as Eikelands generic model. Based on the perceived need for a unified national framework for a process model, Bygg21[4] has introduced the "Next Step standard" (Klakegg et al, 2015), inspired by the English version (RIBAs Plan of Work, 2013). "Next Step" defines eight steps in the building process:

1) Strategic definition (acknowledging a need or problem).
2) Brief development (specification of the contents of the project)
3) Concept development

[4] "Next Step" can be downloaded here: http://www.bygg21.no/no/artikler/bransjesamspillet/bygg21-lanserer-nytt-rammeverk-for-stegene-i-en-byggeprosess/

4) Detailed designing
5) Production
6) Handover (from the contractor to the user)
7) In use
8) Termination

The purpose of such formal breakdown of the building process is manifold. For instance, the definition of formal phases supports the agreement of decision milestones and contract definitions of responsibilities and economical commitment distributed on tasks and activities (Eikeland, 2001).

A very important point in "Next Step", as in much building process literature, is that the phases, or steps, do not (and should not) necessarily follow a sequential order. The order of the steps relies heavily on procurement forms and the chosen project delivery method. They can overlap or co-exist. Eikeland (2001) sees the parallel development of the brief with the design as beneficial. Whereas parallel design and production is a usual model for saving time.

The balance between linear and iterative actions varies throughout the different stages in a building process. The early phase, with the definition of the needs and related concept development, is typically turbulent, creative, open and exploring. Later on, in the detailed design, the process is more goal-oriented, with learning-loops triggering the need for adjusting objectives and prerequisites. In the production phase, the process is almost linear. Decisions and actions can be planned as a network of activities, based on the physical structure of the building (Eikeland, 2001).

Management processes

The management processes include tasks which are of high importance for the building process as such, and for its end-result. Main categories of tasks are project management and coordination, procurement processes, financing, marketing and sale. The management processes follow and enable the core processes from "cradle to grave" (Eikeland, 2001). The next section elaborates on various procurement forms.

Public processes

The public processes relate to formal laws, regulations and more on the authority level (municipality, county, state). Before construction, the client (or an appointed project participant) must typically apply for a building permit. Before the handover to the user, the client needs a use permit. Other examples of public processes are feasibility studies, zone planning and city master planning.

Procurement forms and green procurement

The building process and its outcome is highly influenced by the clients or owners choice of procurement form. Numerous authors have attempted to categorize and systemize the large number of various project delivery methods and procurement forms. We will here use a classification into three main groups, as introduced by Knotten et al (2016)[5].

Segregated procurement forms

The primary feature of these procurements forms is the separation of design and construction. The most dominating example is Design-Bid-Build (D-B-B). In D-B-B-projects, the client contracts with separate entities for design and construction. Typically, the D-B-B-related building process is divided in three sequential phases 1) the design phase (where the client performs detailed design work together with impartial consultants), 2) the tender phase (where the client makes a contract with a contractor, based on best price and other criteria (bidding)) and 3) the construction phase.

[5] The classification is inspired by a recent PMI book (Walker & Lloyd-Walker, 2015).

Integrated procurement forms

The most widespread procurement example in this category is Design Build (D-B). In D-B projects, the architect and contractor form a single entity in contract with the owner. Owners select D-B because it can reduce risk and project costs compared to D-B-B projects (Elvin, 2007). The contractor typically accepts full responsibility for the design (Sinclair, 2011). In Design-Build projects, the contractors are chosen on early design sketches, and the contractors are responsible for the detailed solutions. Other examples of procurement forms in this group are Public-private-partnerships (PPP) and Management Contracting (MC/CM) (Knotten et al, 2016).

Collective procurement forms

Here the focus lies on integrating the project design and the delivery teams by emphasizing collaboration and coordination. Examples of collaborative procurement is Partnering, Integrated Project Delivery (IPD), Competitive Dialogue and Alliancing. Typically, the objectives of such building projects are formulated by involving all parties at an early stage, included the contractor (sometimes even the sub-contractors). According to Knotten et al (2016), some of these examples represents a cultural state or a formal/informal contract arrangement rather than a procurement choice. They have characteristics and elements that can be applied to or combined with other procurement forms.

The challenge of selecting appropriate procurement routes

Erikson & Westberg (2011) described advantages and drawbacks of different procurement routes at the design stage (p.199). D-B-B projects have a solid basis for competitive bidding. However, mutual influence of involved parties is limited. In D-B projects, the contractor has great influence on the design work and the final outcome. In collaborative (collective) procurement procedures, the consultants and the owner cooperate in the development of design (p.199).Collaborative procedures aim at avoiding drawbacks of too late or too early hand over of project responsibility to contractors. Based on extensive findings from previous research, Erikson & Westberg (2011) hypothesised that *"the higher the level of integration between client and contractors in the design stage, the better the project performance in terms of cost, time, quality, environmental impact, work environment, innovation"* (p.199 f).

According to Kadefors (2002), several studies imply that partnering projects are more successful than traditional ones. However, not always; the risk of ending up in quite traditional roles and relationships seems to be substantial. The mechanisms involved in establishing and maintaining trust and co-operative relations in construction projects are complex. Lædre et al. (2006) found that public owners in Norway usually selected the same procurement route as they were in the habit of. They stuck to traditions and did not consider what procurement route suited each single project. Kristensen (2013) state that the procurement situation in Norway, throughout the last four decades, has changed from a situation where Design-Bid-Build was dominant to a situation where Design-Build models are more common.

Bidding forms and criteria for selecting contract parties

We have seen that the clients or owners' choice of project delivery method and related contracts regulates the distribution of responsibility and the organization of the building process. Other crucial aspects of the procurement regime, is the form of bidding (competition, negotiated etc.) and the related criteria for selecting the contract parties (price, qualifications, size and more).

According to Lædre et al (2006), the Public Procurement Regulation in Norway contributes to limiting the selection of procurement procedures. The costs of public buildings exceed mostly the formal threshold of 40 Mill. NOK, which forces public owners to use competition as the bidding form. Interviewees in three Norwegian case studies believed that negotiated biddings or directed negotiations, as would be possible in private projects, often would give "better" results. In such bidding forms, possible solutions can be discussed before the contracts are signed. However, although being forced to use bidding competition, the project delivery model and the chosen contract form still give a variety of choice.

Difi, the Agency for Public Management and eGovernment in Norway[6], is currently initiating an implementation of "Best Value Procurement" in selected pilot projects. Best value procurement (BVP) was, at an introduction made by Difi in January 2016, explained as a method for procurement and project management. In a BVP bidding competition, much weight is put on the bidders' risk management competence, on an extensive documentation of qualifications, and on the ability to create value for the client. The bidder must deliver a six pages description, followed up by interviews. An extensive dialogue between the client and the bidders thus takes place before the contract can be signed.

Green procurement

Lærdre's studies (2005; et al. 2006) of procurement processes in Norway did not specifically discuss implementation of environmental criteria. Nevertheless, the findings revealed that due to public regulations and habits, it was difficult to leave known territory in procurement processes.

Mokhlesian (2014) stated that green construction differs from conventional construction because of its underlying principles and use of environmentally-friendly materials and technologies. He has done a study on how procurers in contractor companies in Sweden adopt green projects. There was a consensus among respondents about the need for close collaboration between contractors and suppliers. According to his study, green purchasing is hindered by the lack of available, reliable knowledge about green products, materials, systems, design, correct green specifications, assessing green requirements, and the availability of green suppliers. Häkkinen & Belloni (2011) found that resistance to new technologies is the main barrier for implementing green projects. Introducing new and efficient processes, decision-making methods, tasks, actors, roles and ways of networking can help resolving this problem. The most important actions to promote sustainable building are the development of clients' awareness about the benefits of sustainable building, the development and adoption of methods for sustainable building requirements management, the mobilization of sustainable building tools, the development of designers' competence and team working, and the development of new concepts and services. To make many of these changes happen, the authorities have a great responsibility, and the public organizations and companies have to be role models (Häkkinen & Belloni, 2011).

Gluch *et al.* (2014) have studied the construction sector in Sweden, and found that environmental work is becoming institutionalized as a strategic part of the companies' business, and environmental management and activities are integrated within the companies' work practices. They see a greater maturity and raised ambitions in companies' environmental actions in general. Legislative pressures have become a reduced driver; instead there is increased pressure from, and need for cooperation with, a larger variety of stakeholders and across disciplines.

Michelsen *et al.* (2009) investigated to what degree Norwegian municipalities and counties had implemented environmental demands in their procurement processes of products and services. Their findings showed that there was a focus on green procurement in municipalities and counties in Norway. Nonetheless, the requirements from the Public Procurement Act were far from implemented in all cases, there were great differences between the municipalities. Large municipalities had significantly more established green procurement practices than small municipalities. The smaller the municipality, the higher the perceived risk. Hojem et al. (2014) investigated one example of a private green building

[6] The "owner" of the public procurement regulation. The agency is overseen by the Ministry of Local Government and Modernisation (KMD). For more information about BVP, see: http://www.bestvalueeurope.com/nl/best-value-best-value-europe

procurement process in Norway. Barriers were found in the fear of extra costs and related risk, the unwillingness to supersede existing building regulations, and the lack of understanding of green building requirements of the involved actors. Success factors for this project were flexibility of the procurement process and contract, as well as the possibility of learning and the implementation of changes during the process. One should also not expect a straight forward process when transcending building regulations, therefore flexibility of process and stakeholders is imperative.

The project organization

Eikeland (2001) regards the project organization as a temporary system. Actors from a number of companies commit themselves, for a limited period, to various tasks throughout the building process. These actors have, in many cases, never worked together before. They are representing different disciplines, interests and internal goals. At the same time, they are obliged to collaborate in order to address the, in many cases, ill-defined and immature aims and objectives of their customer. He also regards the project organization as a dynamic system. Throughout the various stages of the building process, the tasks changes, requiring different actors and roles.

The Next step (Klakegg et al, 2015) emphasizes three overall perspectives or roles: the client or building owner, the user and the executing party. These three main groups of actors in the project organization represents different interests and views on a building project. The client or building owner sees the building process as (among other things) a business case, which should add value to their organization. The users' focus is obviously on the quality, usability and functionality of the building. The executing parties' (the architects, consultants, contractors, producers) focus lies on both delivering a physical product which addresses the requirements of the client and the needs of the user, and on earning money by doing so.

The project organization addresses goals related to both efficiency and effectiveness. According to Eikeland (2001), in an efficient building process the project organization uses a minimum of resources, time and cost to produce the specified result. Efficiency-focused goals demand short term, more predictable, safe and cost-efficient processes for improved productivity. The overall goal is to do the things the right way. Effectiveness relate to the ability of the project organization to create value for the end-users and the society, and to satisfy the requirements, objectives and priorities of the construction industry stakeholders, primarily the clients and project owners. Goals related to effectiveness are about doing the right things. They are often loosely defined and moving targets.

As we have seen in the previous chapter, the procurement forms and related contracts formally regulates the distribution of roles and responsibilities. There are, however, a number of informal, both internal and external factors that also affect the project organization. Moum (2008, p.1) describes that the building process actors are being part of a "highly complex universe where predictable and unpredictable interactions, interrelations and interdependencies between actors and processes create our physical environment". Cuff (1991) views the design process as a social practice. The project management plays a crucial and central role in this practice.

The complexity and characteristics of a building process requires not only "hard" skills related to the professional and technical delivery of each party, but also "soft" skills in, for instance, collaboration and communication.

Trends, innovation and transformations

Throughout the last twenty years, a number of societal, economical or technological trends or challenges have changed the planning, design and construction of buildings.[7] The climate change and energy scarcity are examples of societal challenges, which have motivated the authorities and the construction industry to new thinking and new solutions, and to the birth of the ZEB Center. This trend is interwoven with a growing awareness in the industry about the need to:

- Exploit the potential of the new and enabling technologies. Building Information Modelling (BIM) with the related standards for interoperability between computer systems enables a seamless flow of consistent information across all stages in the building process (BuildingSMART, 2016). Improved coordination, better control and less building failures are some keywords. 3D printing, Internet of Things, Big Data, automation through robots are other emerging technologies that might push industrialization and a paradigm shift in the way we design, produce, construct and use buildings.
- *Shift the perspective from short-termed silo-thinking to a life-cycle focus.* Stimulate to LCC and LCA approaches. A current "hot topic" is circular economy as a driver for a more sustainable industry (McKinsey et al, 2016).
- *Focus on value creation.* Lean construction is among the "new" topics of interest in the industry, with its focus on reducing waste, on the needs of the customer and a better flow (Rolfsen & Jensen, 2014). New and more integrated work practices combined with suitable procurement forms and BIM-technologies is a focus in several Norwegian R&D projects, such as SamBIM[8] and OSCAR[9].

A transformation from the traditional and old into something new and better, enhances the need (and potential) for innovation and change. There are a number of theories of innovation. An example is Rogers' famous model for innovation diffusion (1962, 1995) and his Diffusion of Innovation curve (Fig. 3). Early majority is representing the critical mass. If the innovation proves successful in this group, it will probably become broadly diffused. The step from early adapters to early majority can be regarded as a chasm (Moore, 1991). It is both difficult and critical to "cross the chasm" and succeed with the transition between visionaries (early adopters) and pragmatists (early majority).

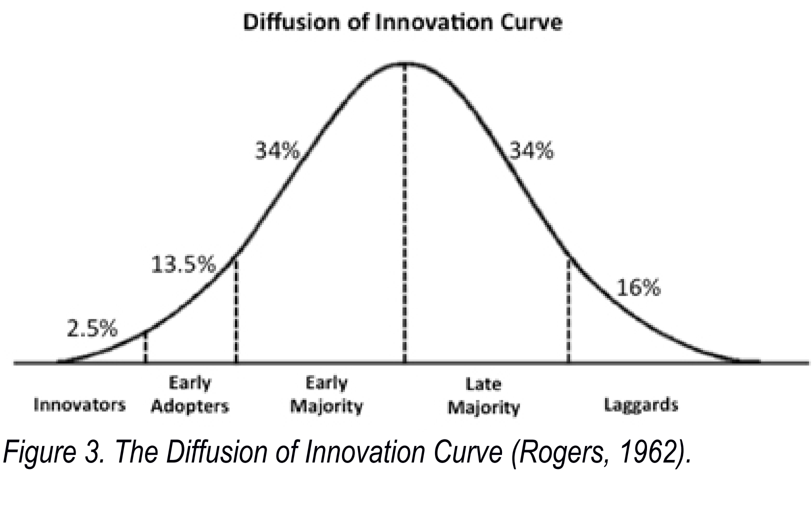

Figure 3. The Diffusion of Innovation Curve (Rogers, 1962).

[7] Globalization, migration and urbanization, the growth of enabling technologies and much more.
[8] SamBim: https://www.ntnu.no/ab/sam-bim
[9] OSCAR: http://www.prosjektnorge.no/index.php?pageId=727

Pilot buildings are efforts to bring new knowledge from innovators through early adopters into the wider building market. In a SINTEF-report discussing market effects of pilot-programs, the authors emphasizes the collaboration between the authorities, the research institutes and innovative companies as crucial, in addition to financial incentives, which important for compensating the risk (Almås et al, 2015). A qualitative interview study with 30 respondents, states that exemplary programs/ pilot buildings may have a major effect on learning and competence of involved organizations, and thus has an important role in preparing the ground for upcoming regulatory changes. Large municipalities also describes participation in pilot programs as a start of an active approach to environmental ambitions for municipal buildings. In addition to the development of skills, there are many indications that the pilot programs affect prices and availability of green building materials, technology development, certification and use of EPD (Environmental Product Declaration).

In spite of the general awareness of the need to improve, enhancing innovation and change in the building processes is challenging. Based on the characteristics of the building process and the project organization, Harty (2005) points out five factors, which are central to understand as a backdrop for the deployment of innovations:

1) Tasks are often conducted in collaboration between several firms, with their own resources, practices and goals.
2) The work is project-based, and there are often large numbers of people and companies involved.
3) The work is dependent on information sharing across organizations.
4) The tasks intersect organizational boundaries.
5) Each involved firm influences the project by its own practices and expectations.

There are many barriers, but there are also many current initiatives with the aim to drive change in order to improve processes, organizations and/or buildings. Such as developing design and construction processes for zero emission buildings, which is the focus of this report. We will wrap up this section by referring to a conceptual framework for better understanding how change initiatives or drivers interact (or counteract) in the Norwegian construction industry (Moum, 2016 and Fig. 4).

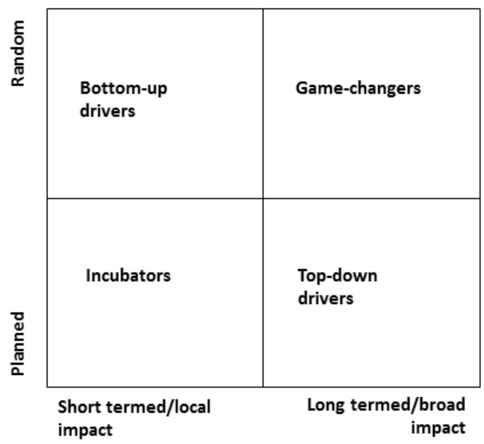

Figure 4. The ecosystem of change-drivers (Moum, 2016)

Game-changers are for instance technology leaps (internet) or shifts in political systems. Bottom-up drivers are typically "one-man" initiatives, based on personal engagement, belief and commitment. Standards, laws, policies and strategies are examples of top-down change-drivers. The public clients have taken an active role in improving building processes by requiring the use of BIM in all their projects. Incubators are collaborative "local" platforms or R&D projects and programmes where for instance research and industry partners join to find new solutions to identified problems (theoretically and/or practically). They are temporary and involving a "closed" consortium of partners (examples: ZEB, SamBIM and OSCAR).

Elements in dynamic development processes
In the pilot studies of ZEB, the project actors and their organizations are facing ambitions of developing zero emission solutions. This might trigger a need to change mind-sets, work methods, contractual issues, roles and more. To implement such changes in an ongoing building project is challenging, and can be viewed as a development project in itself. A research group at Fafo[10] introduces six elements, which should be considered by the initiator in order to succeed with such projects. The six process elements are part of a development model. The research group has identified the elements based on analyses of empirical data collected in a number of research projects on national reforms, local development and change projects in private and public organizations and businesses (shipping, construction, healthcare and more). The development model is also based on theories of employee-driven innovation, and is inspired by classical decision-theories. The model is presented and described in several publications, such as Moland and Trygstad (2006), and Moen and Moland (2010). The six elements are:

1) The purpose, need and legitimacy of the change. Create shared understanding.
2) Concrete goals. Clear communication, shared understanding.
3) Commitment and ownership. Formally and informally. Establish acceptance of the change.
4) Collaboration and involvement. Build a team with the best people, with a clear understanding of the goals and with the possibility to decide how to achieve them.
5) Resources. Time, financial resources, competence (for instance change management competence).
6) Follow-up. Make support available after the implementation of change. Follow up the consolidation of the change and initiate evaluations of its effects.

We will use the six elements as one of the frameworks for the analyses and the discussions in this report.

2.2 User evaluation of energy efficient buildings

The gap
There exists a well-known gap between predicted and actual performance of energy efficient buildings. In some cases, actual performance is quite different from predicted performance (Larsen et al, 2010; Gram-Hanssen & Hansen, 2016; Dokka et al. 2011; Goodhew; 2016), especially for the first years (Hinge at al. 2008). A study by the New Building Institute (2008) found that 30% of LEED-rated buildings (Leadership in Energy and Environmental Design) perform better than expected, 25% perform worse than expected, and a handful of LEED buildings have serious energy consumption problems. These problems may be caused by technical failures, too high expectations, or by inappropriate operation and use. Bordass et al. (2004) suggest that the gap between a building's expected and actual energy consumption "not so much arise because predictive techniques are wrong, but because the assumptions often used are not well enough informed by what really happens in practice, because so

[10] Fafo is an Oslo-based applied research institute which conduct commissioned social research for a wide range of actors combined with publicly financed research. Partner (together with SINTEF and NTNU) in the SamBIM- project.

few people who design buildings go on monitor their performance” (Bordass et al. 2004:1). Hinge et al. (2008) do also point to the use of the buildings, and the meaning of the role and active involvement of building operators and facility management to explain this gap. This explains why research on end users in energy efficient buildings are of great importance.

General satisfaction

A review of previous studies by Hauge et al. (2011) summarizes that general satisfaction is higher in energy efficient buildings than in conventional buildings. Also Berry et al. (2014) found evidence that households in near zero energy buildings attain high levels of thermal comfort, enjoy lower energy bills, and believe their behavior has been influenced by the building and its energy systems. The data are based on interviews from 25 households and monitored energy data from over 50 near zero energy homes.

Why are passive houses and near zero energy buildings experienced as better? Research show that the concentration of mold is lower in passive than in conventional buildings (Schnieders & Hermelink, 2006; Dehli & Bouse (2004). It is also reported lower radon levels in passive / low energy, and lower concentration of other pollutants (Münzenberg & Thumulla, 2003). These findings are closely linked with the use of balanced mechanical ventilation.

Some of the reviewed studies also refers to self-reported health among residents. Residents of passive houses report better health than in conventional houses, or that they have gained better health after moving into passive houses (Schnieders & Hermelink, 2006; Berndgen Kaiser et al., 2010).

Despite many positive evaluations of user satisfaction with energy efficient buildings, there is at the same time a growing concern with overheating in climate zones such as northern Europe and North America. A review of studies on overheating in buildings located primarily in the U.K. concludes with that the focus on overheating has been paid little attention to in practice since the primary focus is on heat-retentive design. There is lack of tradition for using shading, green roofing or shutters in order to reduce the chance for overheating. Thick insulation, single sided ventilation, lack of thermal mass and modern aesthetic expressions favoring large window areas contribute to high indoor air temperatures during summer time (Lomas & Porritt, 2017). Overheating especially in sleeping rooms is pointed out by occupants, and can influence quality of sleep and well-being negatively (Lomas & Porritt, 2017). Also Norwegian studies of passive houses found that residents of passive houses are satisfied with the indoor air temperature in living rooms and bathrooms but that they would prefer lower temperatures in bedrooms. Differentiation of temperature between different rooms is a main concern of passive house occupants (Berge, Thomsen, Mathisen, 2016; Thomsen et al, pending).

Concerns

However, there are also reported some concerns and frustrations among users of passive houses and near zero energy buildings. Some buildings are experienced too hot during the summer, and too cold during the winter. Some operational systems are difficult to understand, or the users have not received sufficient information about how to operate them (Hauge et al., 2011).

Thomsen et al. (2013) conducted qualitative interviews in 6 case studies to develop knowledge on user experiences with passive houses and zero-energy buildings. The focus was on the interaction between the building and the users, specifically on how user interfaces, knowledge, and commitment influence the use of the building and the level of energy consumption awareness. Users in general were satisfied with having a new energy efficient building. However, there were concerns about thermal comfort. Interviewees often experienced the building as too hot in the summer and/or too cold in the winter. This perceived discomfort caused different types of personal actions, which interfered with the intended concept. Misuse or misunderstandings among users in some cases led to lower indoor comfort. New or dissatisfactory design solutions were also responsible for unsatisfactory indoor environmental quality. Many users had received too little information on operational systems or they did not function the way they were assumed to. In order to improve their situation, the occupants often intervened with the planned use. Even though we have no indication that the outcome of these adaptations was negative in every case, a use that is in line with the expectations would still be the preferable option. More detailed information and training will not be able to neutralize the effects of bad design completely. But it would be equally naıve to expect that good design automatically creates the knowledge necessary to use a new technology. The need for more detailed information on operation seems to be more crucial for passive- and zero-energy buildings, than for “conventional” buildings.

The important role of natural ventilation for occupant satisfaction is well documented in the literature. As has been demonstrated by deDear et al. (1997), occupants tolerate a wider range of temperature in buildings when they are able to open the windows. Subjective factors such as expectations toward the type of ventilation (natural or mechanical) account a great deal for experiencing thermal comfort (Brager and deDear, 1998). Nicol and Roaf (2005) describe that people react if a change in the environment causing discomfort occurs. They tend to restore their comfort by putting on cloth or opening windows, and are active participants in the relationship with their environment. Thus, energy efficient buildings that aim at controlling air in- and outflow (either technologically or behaviourally) are likely to face challenges related to occupant dissatisfaction.

The varying results from the user evaluations reflect that the quality of the buildings differs. However, the complaints may also be a result of inappropriate use. Perceived personal control and sufficient information about operation and use is crucial for an overall positive experience of the building. The connection between energy efficiency, use, and occupants’ satisfaction in buildings is more complex than usually assumed.

Understanding the systems
Knowledge and understanding are identified as crucial factors for influencing comfort in other studies: users are much less satisfied when they cannot understand how things work or how to control temperature and ventilation (Leaman and Bordass, 2007; Nicol and Roaf, 2005; Brager and deDear, 1998). The investigations of Isaksson (2009) and Isaksson and Karlsson (2006) of user satisfaction with passive houses in Sweden showed that knowledge about the heating system was an important issue for residents. Some told the authors that they had not received sufficient information about the heating system when moving in. In order to achieve thermal comfort, they tested the system during the first winter, which resulted in varying indoor temperatures and high-energy consumption. Interestingly, people seem to tolerate more discomfort if they know how the building is supposed to operate (Leaman and Bordass, 2007).

Mlecnik, et al. (2012) analyzed mainly German, Austrian and Swiss post-occupancy evaluation research results on nearly zero-energy dwellings and undertook a survey of occupants of nearly zero-energy houses in the Netherlands. The study determined how various comfort parameters, such as winter thermal comfort, summer thermal comfort, indoor air quality and acoustics, information provision and control parameters were related to positive or negative end-user appraisal. They found that summer comfort design and the quality of the information about the heating and ventilation systems were critical factors, which must be addressed to improve user satisfaction in nearly zero-energy dwellings.

High expectations
User expectations to comfort in passive houses and zero energy buildings tend to be higher than in conventional buildings due to high demands to air tightness, thicker insulation layers, resulting in higher surface temperature, and regulation of air exchange rate through balanced ventilation (Thomsen and Berge, 2012). It is, however, not that simple to predict and quantify individual comfort experience

through measuring temperature, since people experience thermal comfort in relation to their behaviour, habits, and experiences (Nicol and Humphreys, 2002).

Users in the case studies by Thomsen et al. (2013) also had high expectations regarding the performance of these new buildings. These expectations were often created through media and through the information they have gotten through the operational staff/project managers. Brown and Cole (2009) found that high-performance expectations met with lower perceived performance leading users to complain more, or to take matters into their own hands to influence their perceived comfort by applying other solutions than the ones given in the building.

However, Leaman and Bordass (2007) state that users tend to have a higher tolerance of deficiencies in “green non-residential buildings” than they do in buildings without an energy efficient profile. This implies that image and process mean something in the evaluation of the building.

Motivation

What is also important to keep in mind, is that the energy profile of buildings is usually not the primary motivation for people to live or to work in these places. That is also a reason why they may not behave in the most energy efficient way. Users in new buildings may also be mostly interested in having a completely new building, whether it is energy efficient or not (Hauge et al., 2011). However, it can be supposed that in the long run, the energy profile may also have an influence on knowledge and awareness of these topics, as indicated by Vale and Vale (2010). In a Norwegian study, the low-energy concept of housing was important for only one-third of the buyers. Interestingly, later on most residents answered that living in a low-energy building had made them more aware of energy use and environmental friendly behaviour (Kleiven, 2007).

Domestication

One way to analyse user experiences of zero emission building, is the framework of the domestication theory. Domestication theory is a multidisciplinary social science approach emphasizing the importance of interaction between society (policy, tools, contracts), technology and material conditions, and user needs, motivation and daily life (Shove 2003a, 2003b; Throndsen et al., 2015). This perspective helps us understand how knowledge and information is selected, transformed and put to use in people’s everyday lives. Domestication theory is about the process of "taming", meaning bringing something into the fold of the domestic sphere (Throndsen et al, 2015). In the late 1980s, domestication was first employed by Roger Silverstone et al. (1992) in his studies of media consumption. Instead of a simplistic focus on “what the media does to people”, Silverstone and his colleagues sought an understanding of users’ relationship with media technologies that resembled active use more than passive consumption. This provides users with an agency of their own, instead of an understanding of users as victims of “bad performance” of technology or passive beneficiaries of cunning design (Berker, 2011).

Technologies are appropriated and integrated more or less pervasively in the seamless web (Hughes 1988) that constitutes everyday life in modern societies. In the concept of domestication, the conjoining of users with technological artefacts is characterised by reciprocity; users form relationships with the technologies they use (Lie & Sørensen, 1996). The focus on the relationships between users and artefacts may become especially useful in instances where designers miss their target and technology consequently fails. These can then be cases of failed domestication, where users may have “failed” to reproduce the intended use design of the object, or what is often referred to in Science and Technology Studies as "script" (Akrich, 1992). Understanding technologies as a text, the instructions and explanations for interpretation leads to a view in which the designer presents to the user a “correct” use (Woolgar, 1991). In successful “readings” of a technology, the intended use on the part of the designer is what is also understood by the user. Domestication theory deviates from this view by extending on the “reading” activity on the side of the user. Berker (2011) states that as design contains “user representations", i.e. ideas about what the user looks like and what s/he does, it is necessarily subject to the users' negotiations and may even meet outright opposition. Mismatches between design and use context are common. Mismatches, however, is not the same as bad use. Good results may still be achieved, even if there are mismatches between intentions and use.

Empirical studies of domestication processes have shown the importance of practical aspects related to the technology, as well as cognitive and symbolic aspects of use. To domesticate issues of sustainability, people need to negotiate the meanings and practices of these matters in a dynamic, interactive manner that makes sense within their own cultural framework (Sørensen et al., 2000). Strategies of domestication – or, in this case, sense-making and appropriation of sustainable and energy efficient buildings – take place in three main domains:

1. the practical,
2. the symbolic,
3. and the cognitive.

First, people develop energy practices that they consider appropriate. How can they act upon the challenges they perceive? Practical aspects address the actual use of a technology, its practical workings and how they fit into existing practices (or not).

Second, regarding the symbolic dimension, they interpret sustainability in buildings in ways that allow them to make sense of these matters, to uphold their identity and to be helpful to the public self-presentation they wish for. In the symbolic domain, a higher "value" (status) may be attached to the use of the object, which is capable, in some instances, of transmitting parts of the users' identity to their surroundings.

Third, and finally, these issues need to be cognitively appropriated to allow people to make use of available technologies and behavioural options (Godbolt, 2014; Sørensen, 2006). Cognitive aspects are related to learning; how and in what ways users are given a chance to get to know a technology, how they come to learn or teach themselves, how to use it - and, of course, whether learning occurs at all (Sørensen, 2005, 47). Analysing the domestication of technologies, architecture and knowledge that constitutes sustainability, thus means studying the development of practices, the construction of meaning and the processes of learning (Sørensen et al., 2000; Sørensen, 2006).

3. Method

3.1 Qualitative case studies

Case studies
Case studies are the preferred strategy when the focus is on a contemporary phenomenon within a real-life context. Case studies aim at explaining a complex reality in contrast to quantitative methods focusing on a few chosen variables (e.g. experiments or surveys) (Brinkman & Kvale, 2015). Quantitative methods, as surveys, aim at collecting numbers and offers statistics to describe reality (Tang & Bhamra, 2012). We have chosen an explorative approach, which enables us to go more in depth and better understand the challenges in the process towards zero emission buildings. The objective was not to test hypotheses. The low number of existing zero emission buildings, and their variance in size and context, makes such a test meaningless. Instead, we sought to describe and understand the barriers and possibilities in the processes leading to zero emission pilot buildings. Case studies are in depth studies, which have to be understood according to their reality context and uniqueness. The context cannot be left out when analyzing results (Thomsen et al., 2013) and the focus is on learning for subsequent processes taking place in similar contexts (Flyvbjerg, 2006).

Analytic generalization
The results from any case study do not claim to be representative for an underlying population. However, they can be generalized analytically, meaning that the findings from one study can be used as a guide to what might occur in other situations (Kvale, 1996). By providing detailed information about context, specifying supporting evidence, and making arguments explicit, the researcher allows readers to judge the soundness of the generalization. This generates concrete, practical context-dependent knowledge.

Pilot studies
We use the term *pilot studies/ pilot buildings* when mentioning the case studies in this report. This is common practice when case studies are already conducted in previous research/ the same research project (see ZEB-report no.1, Thomsen, et al. (2011). The pilot studies aim at trying out new and innovative solutions based on the experiences from the case studies. A common denominator of the pilot projects of ZEB, is the support given by researchers and scientific experts.

Types of data
A case study relies on multiple sources of evidence, often with a mix between quantitative and qualitative methods (Yin, 2003). Here, the main source empirical data are interviews with experts in different roles in the pilot studies, seeing the building project from different angles (Bogner et al, 2009). In addition, we have studied media reports, documents, meeting minutes and email correspondences to be able to describe the pilot buildings in detail.

3.2 Interviews

One-to-one- and group interviews
We have conducted both one-to-one interviews and group interviews. The interviews were done as similar to a normal conversation as possible. We used a semi-structured interview guide, which consisted of a list of topics that we made sure would be touched during the interview. If the interviewees talked about any of the subjects unasked, we followed up their association chain.

Group interviews often generate constructive and extensive discussions (Kitzinger, 2008) due to their nature. The input from one informant may generate ideas and thoughts within another informant, and the results are therefore often richer than individual interviews. Especially within evidence-based design, focus-group studies show insight in user behavior and produce important contributions to sustainable innovation (Tang & Bhamra, 2012). The focus groups have had from 2 to 5 participants. Number of participants in this range will usually generate good discussions and plenty of contributions, and give rom for everybody to talk (Kitzinger 2008).

The interviews lasted for about one to two hours, and were recorded and transcribed based on notes and recordings. In this way, we got the opportunity to use direct quotes from the interviews in the discussion of results. Themes and opinions were grouped, analyzed and discussed.

Interviewees

We interviewed between four and eight persons per case study (Table 1). Either in individual interviews or in group interviews. The interviewees are representing various parts of the building process, thus shedding light on a broad range of relevant issues. The interviewees are typically clients and owners, architects, consultants, contractors and users. In total, we interviewed 23 persons.

Table 1. Overview of interviews and interviewees per pilot project.

Pilot project	Multikomfort	Heimdal VGS	Skarpnes	Visund, Haakonsvern
Individual interviews	2	2	6	2
Group interviews	1	1	-	3
Number of interviewees	5	4	6	8
Role of interviewees	Two representatives from project owners, project manager, contractor, and architect	Project owner representatives, architect, consultant and contractor representative	Project manager and contractor, architect, consultant, users	Project managers (client), user representative, managers and operating staff in design team and contractor.
Time	June 2015. 6 months after hand-over.	April 2016	October 2015. Hand-over was 2014/2015.	April-Mai 2016. 4-5 months after hand-over. Supplemented October 2016.

Research ethics and anonymization

Recognized norms for research ethics (NESH, 2016) require the respect of informant privacy. In this report, the citations from the interviews are anonymized by relating them to three main groups of interviewees: "client", "executing party" (e.g. architects, consultants, contractors) and "user"[11]. These three groups are representing different viewpoints for evaluating the building process and the building. Differentiating the citations in this way gives the reader a better understanding of their context. The interviewees have accepted the use of citations in this report. The authors of this report is responsible for the translation of these citations into English.

Interview guides

Interview guides from research projects with similar topics inspired our interview guide, such as EBLE – Evaluation of energy efficient housing, and ZEB – procurement processes. We also invited the leaders of the pilot projects to suggest topics they had a special interest to evaluate.
Interview topics:

[11] Occasionally, the informants are holding more than one role. In the Multikomfort-project, some informants are both clients and supplying consultants.

- Person/ role
- Pilot project description
- Ambitions / aims
- Organization and collaboration
- Learning and knowledge
- Costs
- Societal context, municipality etc.
- Evaluation of solutions

We have enclosed the interview guide as an appendix to this report.

3.3 Reflections on methodological limitations and weaknesses

The qualitative case-study strategy with interviews as an important data-source is regarded as the most appropriate method for process-evaluation in real life situations (see the introduction of this chapter). It is, however, important to be aware of some its limitations or weaknesses, and to take precautions.

Firstly, the time at which the interviews are carried out, might play a role in how the interviewees perceive the processes and the end-result. The interviewees might forget or regard negative experiences as less negative from a retrospective view. Positive reactions and opinions on the resulting building might affect the interviewees' retrospective view even more. In contrast, if the interviewees are interviewed "in action", in the middle of an ongoing conflict or a challenging period, this might lead to a biased focus on negative issues. We therefore have chosen to carry out the interviews at similar times or phases in the pilot projects (when possible). In Multikomfort, Skarpnes and Visund, we interviewed the project team after the completion of the projects. The user evaluations of Skarpnes and Visund are both based on interviews carried out a few months after the handover.

Secondly, all these projects are appointed pilot projects in an ambitious research program. This fact might affect the data and even the processes themselves. The extra attention and visibility of such projects might motivate the project team members to be more patient and to do an extra good job. Hence, the findings might have been different in studies of "normal" projects. In order to compensate and making this issue more transparent, we asked the interviewees to consider how being a part of ZEB has affected on them and their work. Another possible side effect of being a pilot study is the public attention, which generates a "pressure" of being a good role model. Sometimes pilot project are not as successful as expected. In such cases, it might be challenging to avoid that interviewees or case-owners wish to hold back negative data or even restrict what to be publically presented or not in the case-reports. We discuss and reflect on the effects of being pilot studies throughout this report.

Thirdly, it is challenging to achieve a high level of anonymization in visible and well-known pilot projects where "everybody knows everybody". We have therefore been particular careful in the way we use citations, by relating them to three main groups of interviewees (client, executing party and user) instead of referring to their specific profession and role. The interviewees have also had the possibility to check quotes and to correct misunderstandings.

3.4 Pilot buildings for evaluation

The ZEB Centre has 9 pilot buildings (Andresen, 2017).

We have evaluated the building process in four of these pilot projects. In two of them, we have also explored the early use phase. Heimdal VGS is still in the design phase (2016). The ZEB House Multikomfort is a showcase for new products and installations, and not used for housing purposes. The building is situated in an industrial area, and has to be moved to a housing area to function as a dwelling.

Throndsen et al (2015) has already published a similar study of one of the other ZEB pilot buildings. The three remaining pilot projects have not been subject to these kinds of evaluations. At the time of writing they have not reached beyond the early stage planning (not yet started the design process) or they have not been ready for evaluation for other reasons. These buildings will be subject to evaluation in subsequent reports.

Table 2. Facts about the four selected pilot buildings (Andresen, 2017)

	ZEB House Multikomfort	**Heimdal VGS**	**Skarpnes residential development**	**Visund, Haakonsvern**
Location	Larvik	Trondheim	Arendal	Bergen
Type of project	Single-house, demonstration project	High school and sports hall	5 Single-family residential buildings	Office building
Heated floor area	201.5 m²	26 300 m²	154.2 m²/house	2031 m²
Client	Brødrene Dahl and Optimera	Sør-Trøndelag Fylkeskommune	Skanska	Forsvarsbygg
Project delivery method	Partnering	Design-build with prequalification and partnership contract	Design-build	Design-build
Architect	Snøhetta	Rambøll and KHR	Rambøll	LINK Arkitektur, (preliminary project), ABO Architects (detailed design)
Consultants	Brødrene Dahl and Optimera	Rambøll	Øivind B. Berntsen	Multiconsult (preliminary project), COWI and Rambøll (detailed design)
Contractor	Espen Staer	Skanska	Skanska (design-build contractor)	Veidekke (design-build contractor)
Year of construction	2013-2014	2016-2017	2014-2015	2015
Level of ambition[12]	ZEB-OM	ZEB-O+20%M	ZEB-O	ZEB-O ÷ EQ

[12] *See ZEB-definitions:

4. Case-study summaries

In this chapter, we present a brief summary of the findings made in the four case studies. We recommend reading the full report from each pilot project. These reports can be found in "Casebeskrivelser av fire norske ZEB pilotbygg - byggeprosess og brukerevaluering" (Moum, Hauge &Thomsen, 2017).

4.1 ZEB-house Multikomfort

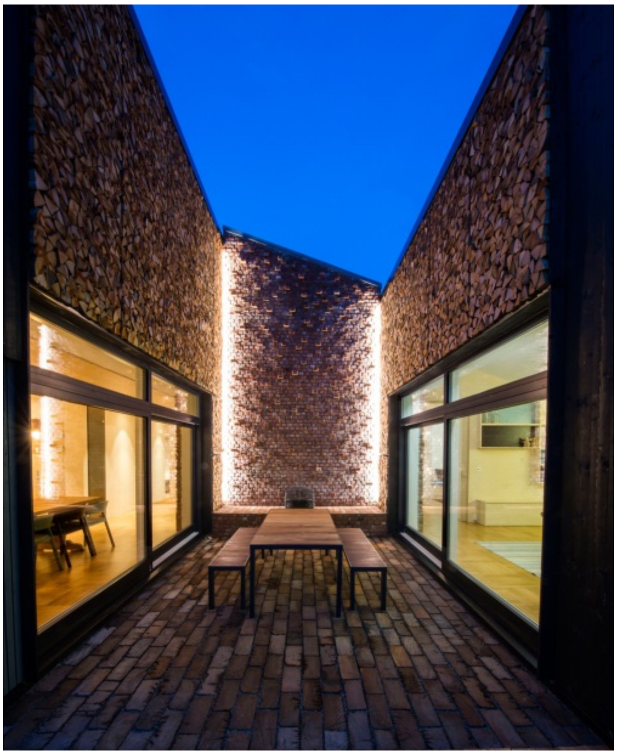

Figure 5. Multikomfort House (Photo: Brødrene Dahl og Optimera)

Localisation:	*Ringdalsskogen close to the City of Larvik, Vestfold County Authority*
Project type:	*Detached house, demonstration project, Show room for products*
Heated floor area:	*201.5 m²*
Owner:	*Brødrene Dahl and Optimera*
Architect:	*Snøhetta*
Consultant:	*The owner incurred as consultants*
Contractor:	*Espen Staer AS*
Construction year:	*2013-2014*
Energy level:	*ZEB-OM*

All of the involved partners had high expectations and clear energy ambitions for the project, and the team is described as very competent. As early as by spring 2015, the house had 2000 visitors and had won a European design price. All partners valuated the project as exciting, interesting, innovative and important for their personal career as well as for the image of their companies.

Ambitions
Design and energy ambitions had been high from the beginning, and were constituted in the ZEB-OM ambition level, which includes the emission from operational energy and material use in the carbon

footprint analysis. Life Cycle Assessment (LCA) was applied as a tool to evaluate the GHG emissions mainly using product specific data found in Environment Product Declarations (EPDs), and the partners described the focus on embodied material emissions as demanding but interesting. This procedure helped gaining more control over subcontractors and transparency in the supply chain. The involvement of key persons from the beginning and the researchers from the ZEB centre were important success factors.

Organisation and Management

The organization of this project was unique, due to the two suppliers of building materials as owners. The project team consisted of two representatives from the owners, a contractor, a technical design leader and an architect. An interdisciplinary approach was used to ensure the best possible results. Experts and representatives from executive companies, craftsmen and research institutions were included in planning meetings, workshops, or were consulted during the design process. Challenges in the project were observed with regard to the active participation of craftsmen and executive companies in the design process, the total cost for working hours, a challenging building site and time pressure at the end. The choice of materials was the most difficult task due to the requirement of materials with EPD documentation for the LCA study. On the other side, the partners appreciated the good management, the appropriate communication and the extensive creation of knowledge. Workshops were the main platform for cooperation, and solutions were already developed in smaller groups and discussed and adopted in the workshops.

The collaboration within the project group was regulated by a partnering contract. This was perceived as an appropriate model for knowledge creation and flexibility to the adaptation of new solutions during the project. It required trust between the partners, as the focus lay on cooperation instead of personal interests.

Knowledge

The involved partners constituted themselves as adequate expertise already at the beginning of the project, but gained new knowledge with regard to carbon footprint, EPDs, material usage, re-use of materials and technical solutions for isolation and air resistance. The researcher and consultants brought in important knowledge about energy related issues and sustainability. All of the partners will use their extended expertise in new projects. One of the interview partners stated that a construction manager with a broader environmental background could be more supportive for the project.

Costs

According to the interviewees, the construction of the house was expensive, due to several reasons. The architectural design and the outdoor area were expensive – in particular because of the indoor staircase, swimming pool, sauna and stone walls in the garden. As expected, planning costs were higher, since the architects have been integrated not only in the pre-project but also during the construction phase in the follow up of the design process. The interview partners described a pilot project as naturally more intensive, as it always needs more planning effort due to insecurity, a new type of building and a change of perception among the involved partners. The focus on CO_{2eq} emissions was also pointed out as a driving force for higher costs, as new solutions are always more expensive and/or time consuming. The partners stated that it was difficult to estimate the costs in advance due to the insecurity within the project. But the focus was not on costs. The building was seen more as a research project than as a construction project. Selling the house on the market was never planned.

Societal Context

With regard to financial support, the building owners asked for support in the 'Skattefunn' program of the Norwegian Research Council (NFR) for product development, which was granted for a subproject. They considered to ask for support from Husbanken and Enova. But due to negative experiences with Enova funding due to high documentation requirements, they did not apply for it. The municipality of Larvik was involved in parts of the project and approached it positively. The project was a pilot project within the ZEB centre. The lack of knowledge about other national pilot programmes like FutureBuilt and Framtidens Bygg was probably the reason why the project did not participate in them as well. When it comes to legislation, the partners are engaged in the discussion about guidelines for the construction industry on behalf of energy standards. They advised to focus less on passive house standards for future TEK revisions, but more on qualitative elements like daylight and acoustics. They name the refurbishment of the existing building stock as one of the most important challenges in the future. The certification system BREEAM was evaluated as a good system, but not appropriate for buildings or this project, as it wouldn't contribute to a better result since the energy standards were already really high. The interview partners stated a positive effect from the used EPDs as a main background data source for the LCA study, as they influenced the perception and behaviour of the suppliers directly in order to apply these methodologies on their products.

Evaluation

The interview partners evaluated the architectural design as positive, especially the spatial experience inside the house. The house was designed to offer a high living quality, and therefore the technological systems are hidden, the windows can be opened and a fireplace is installed. Several advanced technologies and building materials were used, such as a double passive house wall and the re-use of grey water. The current energy analyses were in line with the estimated energy usage. One of the partners commented that the planning effort for several solutions and the management on the building site could have been more detailed, to avoid time consuming adaptations. The programmes BIM, Simien and Rhino were used for simulation and calculation. An excel-based GHG emission calculation tool that has been developed by the ZEB centre was used by the researchers to calculate CO_{2eq} emissions from the operational energy use and embodied materials emissions.

Conclusions

The partners were satisfied with the results and named as success factors the interdisciplinary team and its involvement in the whole process, the cooperation model, high ambitions and trust among the partners, EPD to improve transparency and encourage the use of materials with lifecycle information and the connection to the ZEB centre.

4.2 Heimdal VGS

Figure 6. Winning design Heimdal high school (Illustration: Rambøll)

Location:	*Heimdal, Sør-Trøndelag County Authority*
Project type:	*High school and sports hall.*
Heated floor area:	*26 300 m²*
Owner:	*Sør-Trøndelag County Authority*
Architect and consultant:	*Rambøll Norge*
Contractor and consultant for energy and environment:	*Skanska*
Construction year:	*2016-2017*
Energy level:	*ZEB-O+20%M*

Most of the involved partners had high expectations towards the project and appreciated the gained knowledge, which has a positive impact on their personal career.

Ambitions

The building owner's ambition was to build school with good indoor environment and low GHG emissions, and the project was therefore planned with passive house standard NS 3701 for business buildings. All of the involved partners were aware of the challenges implied by such a high standard, e.g. as the costs or difficulties of implementing the planning. They regarded a pilot project as naturally more expensive, but appreciated the chance to learn. Some partners criticized the lacking consideration of energy consumption per person, and the lacking consideration of the multiple purpose of the building in use.

Organization and Management:

The project group consisted of representatives from the building owner, contractor and experts with different backgrounds within energy and environment, building physics and other engineer subjects.

Representatives from the ZEB centre were involved as consultants in the process, and helped e.g. in creating the call for the competition as the ZEB criterion was new for all partners involved.

A new type of competition -the 'two-step competition-based dialogue'- was chosen to enable a more creative, flexible process with stronger involvement of the executing parties and the user, and control of the project owner. This competition consisted of four phases. In the first pre-qualification phase, 8 applicants were chosen to develop a project design in strong cooperation with the building owner. An open workshop in cooperation with the ZEB centre focused on the energy and environmental aspects in the competition. In the second stage, three applicants developed a more detailed plan in cooperation with the building owner. A jury selected - with regard to price, architecture and realization of energy standard - one team that continued. In the third competition phase, this team entered into a collaborative contract with the building owner. The project design was concretized and a user coordinator was appointed to coordinate between the demands of the users (employees and students) and the project team. The result of this cooperation phase was the pre-project: a revised project design which consists of precise solutions and binding costs, completed in March 2016. The fourth – main project – phase started in April 2016 and was expected to be finished on completion of the project in 2017. In the main project phase, a general contractor will be established.

With regard to the described competition process, the contractors emphasized the strong focus on energy and environmental aspects as new, and criticized the insufficient communication about the weighting of the ZEB criterion for the proposal evaluation as well as the problems to choose the appropriate materials with regard to the energy-standard. The cooperation contract is evaluated positively by all involved partners. It ensured the active contribution of the owner, the adaptation to new solutions and is in general appropriate for the design of projects with high ambitions and unknown solutions. The process demanded an open dialogue between the partners and aspects like motivation and responsibility, and were pointed out as important success factors for such a project. The cooperation contract required special attention with regard to communication, and therefore a contractor representative was appointed to organize the communication process between the several contractors and the project owner.

The owner signed an energy performance contract (EPC) with the construction company, who is thereby responsible for the operation of the school within the first 5 years. If the energy consumption will be over the estimated ambitions, the construction company have to take a share of the additional costs.

Knowledge
The interviewees evaluated the creation of knowledge differently. The building owner constituted a positive effect on all involved partners with regard to competitive advantages and expertise, e.g. due to several workshops in cooperation with the ZEB centre. The contractors criticized the lack of knowledge in some areas, but stated the creation of knowledge in specific areas like the optimization of materials and structures.

Costs
The interviewees were aware of the higher costs for a pilot project. In this case e.g. due to the installation of a CHP plant. The owner asked ENOVA for financial support. The cost of the project was not described as an important factor in the project planning process.

Societal Context
Financial support for innovative projects was perceived as an important factor for the development of new solutions by the interview partners. They criticized the missing standard for cooperation contracts and passive buildings. BREEAM was evaluated as a good standard despite it was not used in this project. The public authority as building owner had a high societal responsibility.

Evaluation

The architecture of the school was designed as flexible as possible to adapt easily to future changes in user demands. The climate footprint was an important aspect when evaluating architectural solutions and the choice of building materials. While the project owner was satisfied with the results so far, the representatives from the construction company criticized the quality of the architectural solutions and described the discussions about architectural solutions as exhausting.

Technological solutions like the energy and ventilation system had been adapted several times during the first three competition phases. In the end, a biogas based Combined heat and power (CHP) unit , roof mounted PV system and a ground source heat pump were chosen as energy production systems. CHP was a relatively new solution in Norway, and was criticized by the construction company representatives for its high costs (1 Norwegian Krone/kWh). The ventilation system was organized in several smaller systems. This simplicity was demanded by the owner and criticized as difficult to steer, and therefore as more expensive by the construction company representatives. With regard to the uncertainty about the chosen technological solutions, an evaluation of the operated building is essential.

Conclusion

The building project is not completed, but for the moment it looks like the defined ZEB ambitions could be realized. The cooperation contract is the most important success factor for this project.

4.3 Skarpnes residential development

Figure 7. The Skarpnes dwellings (photos: SINTEF Byggforsk)

Location:	*Skarpnes, Arendal Municipality*
Project type:	*5 single family residential buildings*
Heated floor area:	*154.2 m² per house*
General contractor:	*Skanska*
Consultant HVAC[13]:	*Øivind B. Berntsen AS.*
Architect:	*Rambøll Arendal*
Construction year:	*2014/15*
Handover:	*2014/15*
Energy level:	*ZEB-O*

The zero emission houses in Skarpnes, Arendal municipality were completed in 2014/2015 as the first houses with this low energy standard in Norway. The passive house standard NS 3700 was taken as basis, but the implementation of technical solutions and the consumption of renewable energies brought the project far beyond the standards in NS 3700. It was the first time the involved companies worked together in this field and – as the interviews pointed out – a lot of new knowledge was generated, and technological solutions were developed within the project. Due to technical and cost related challenges, the construction was changed and adapted during the construction process. In the end, five of the 17 planned houses were built with the zero emission standard, while the other 12 were built with the TEK 10 standard.

Part 1: Design and construction

<u>Ambitions</u>
The idea for the project was born between the construction and the consultant company, who had worked together before on a passive house project. Their intention was to drive the project of housing construction in Skarpnes further beyond the passive house standard. All of the three representatives highlighted the importance of key persons for the starting and implementing phase of the project. Despite problems during the construction phase, the high ambitions tied to the zero emission standard were never doubted, and all interview partners were satisfied with the outcome of the project.

[13] Heating, ventilation and sanitation engineering

Organisation and Management
The establishment of a general contractor was chosen as the implementation model with the construction company as a central actor with strong ties between the different partners and disciplines. Despite an in general positive evaluation of this model, one of the partners pointed out that the interdisciplinary work could be more intense. The interview partners had a positive experience regarding the combination of team members from the practical and theoretical side and pointed out that this helped to get a reality check for the discussed ideas.

Knowledge
All interview partners saw a high impact on the extension of knowledge as well for themselves and for their companies. The participation in a further training about photovoltaic cells for example, enabled the representative from the construction company to install them on his own.
For the companies, this pilot project in Skarpnes was not profitable. However, the interview partners valuated it as a motor for the creation and transfer of knowledge, and highlighted the impact for further projects.

Costs
The interview partners valuated the pilot building project with a zero emission level for themselves and their companies as highly important although it was financially not profitable.
The total cost of the zero emission houses were in general higher than houses build with the TEK10 standard. The five zero emission houses in Skarpnes were sold for ca. 4.8 million NOK (154.2 m^2 heated floor area), and the 12 other -slightly bigger- houses build with TEK10 standard were sold for 3.9 to 4.2 million NOK. The price for the zero emission houses would even be higher without the 300 000 NOK which the construction company Skanska got for the PV on every house from ENOVA.

Due to more expensive building materials and a longer construction phase, the prices were higher for the zero emission houses. The hydronic system with ground source heat pumps alone counts for 200 000 to 300 000 NOK, as the photovoltaic cells do for 140 000 to 160 000 NOK of the extra costs. The windows with three layers as well were an extra cost factor. The construction of the zero-energy houses counted for 1 200 hours in comparison with 700 hours for the TEK10 standard houses in Skarpnes. An improvement in the construction process of the walls helped to reduce time (approx. 120 hours) and costs for the construction of the last two houses.

Different possible technical solutions were evaluated by calculations, and some of them - as solar collector and grey water recycling - were excluded during the planning process due to their costs.

Societal Context
All of the interview partners believed that zero-energy houses will be more common among people in 10 years. One of the biggest problems is to convince people to use photovoltaic cells, as they are expensive. Without the financial support of Enova in the project, the houses would have been even more expensive and probably not realised as the interview partners emphasised. Arendal municipality was in general considered to be dedicated and future-oriented, but they neither participated in the process, nor used the zero emission houses as a pilot project for marketing purposes.

Evaluation
The zero emission criterion constrained the architectural freedom (e.g. bracket of the roof, size of the house), but the architect stated that there were just small differences between the zero emission and TEK 10 houses. The general appearance of the house was connected to the 17th century houses with asymmetric roof in the neighbourhood. This was decided at an early stage of the project, and the architect wondered if the architectural expression would have been different if he had been a member of the project team.

Other measures were adapted. The thermal system were configured to efficiency level 4. Hot water is produced by a ground source heat pump and stored in a 180 l tank at 55 degrees. Air convectors were installed in the hall of the first floor. All houses have underfloor heating in the bathrooms, utility room, entrance hall and some at the corridor at the first floor. The consultant pointed out that underfloor heating is not appropriate with regard to efficiency and energy-friendliness, but it was highly requested by the tenants.

Conclusion
The location of the zero emission buildings was crucial due to the higher price (longer construction time, costly technical solutions and finding new solutions) and the demand for a market. Financial support was important in order to realize some technical solutions (s). In general, pilot projects are usually not profitable for the involved enterprises, but the knowledge gained through the pilot projects is highly valuable. The general contractor model proved itself as an appropriate organisation form. Key persons and good communication between the stakeholders were evaluated as an important factor for a successful project.

Part 2: Early use phase - evaluation by the residents

The interviews were conducted with residents of the three zero emission houses in Skarpnes at their homes. All of the residents moved from older buildings stock in Oslo and appreciated the zero energy building standard and the better cost-benefit ratio in Arendal kommune. The family situation differed: one couple had one child, another had two, and the third couple had no children. They all moved in during spring 2015, half a year before the interviews were conducted.

Indoor temperature
All of the residents were very satisfied with the indoor temperature – both summer and winter - and the technical solutions to control it. Sometimes, when the outdoor sun protection system was going down automatically, the residents opened it up again, as they preferred direct sunlight. Some opened the windows to cool down the room and for fresh air supply, especially in the bedroom at night.

Indoor Climate
The inhabitants perceived the indoor climate as very good. Especially the air quality, with less pollution and dust, as one of the tenants is allergic. They used the ventilation system on level one or two and set it on a higher level when they were expecting visitors. The sound of the ventilation system and the missing 'communication' between the different energy systems was perceived as an optimization potential.

Usage of the house and its technology
The technological systems for temperature and ventilation offers a wide range of choices, which the tenants were appreciating. However, after moving in they were insecure about the possibilities offered by the systems. The tenants of one house were using web applications to control the heating and ventilation system, e.g. when they were abroad or for monitoring the solar energy production. All of the inhabitants were aware of energy consumption and two households changed their energy consumption behaviours, but to a variable degree. Some were using the "absent button" regularly, and the dishwasher or washing machine when solar energy was produced, while others to a lesser degree were changing habits but installed low energy devices (A+++) in the house. The introduction into the technology of the house was evaluated as very poor by the residents, especially when it comes to problems with the system.

Interest in environmental technology
The inhabitants had different environmental attitudes when they bought the houses, but all were satisfied with the zero emission houses. Especially the production of solar energy was evaluated positively. Some were planning to go in for covering their total energy consumption by solar energy. They criticized the lack of financial incentives to install solar energy systems, and that the produced energy is selling for a low price (0.18 Norwegian Kroner under the purchase price of 0.24 Norwegian Kroner).

Conclusion
All of the inhabitants were satisfied with living in the zero energy houses and appreciated the good indoor temperature and climate. They got used to the technical systems after a time of insecurity, and some changed their behaviour with regard to optimizing energy consumption (e.g. technical devices run by self-produced solar energy). They criticized the poor introduction to the technical systems of the house and the lacking financial incentives for solar energy systems.

4.4 Visund, Haakonsvern

Figure 8. The Visund building (Photo: Åsmund V. Sjursen)

Localisation:	*Haakonsvern in Bergen, Hordaland County Authority*
Project type:	*Office building*
Heated floor area:	*2031 m²*
Client:	*Forsvarsbygg (The Norwegian Defence Estates Agency - NDEA)*
Architet:	*LINK Arkitektur (preliminary project), ABO Architects (detailed design)*
Consultant:	*Multiconsult (preliminary project), COWI and Rambøll (detailed design)*
Totalentreprenør:	*Veidekke*
Planning phase:	*2011-2014 (including proceedings in the Ministry of Defence)*
Construction year:	*2014-2015*
Hand-over:	*December 2015*
Energy level:	*ZEB-O÷EQ*

The Visund building provides office spaces for the Logistics organization of the Defence ("Forsvarets logistikkorganisasjon"). The work space (around 100 work places) is organized as a mix of open space offices and cell offices. The three-storey building has a photovoltaic system on the flat roof. Furthermore, demand-controlled ventilation with cooling and air-heating, supplemented by radiators in the offices (mixing ventilation with active diffusers). It is connected to a sea water based heat pump at Haakonsvern, which provides thermal heating and cooling to the building.

The client, a ZEB-partner, appointed this project to a pilot project of the ZEB Centre. All interview partners described the project as an important learning arena, making possible the development of valuable competence for future projects and personal career.

Part 1: Design and construction

Ambitions

By being a pilot project and through the enthusiasm of key persons from the client and the architectural company, the ambitions were raised from energy class A to a 0-energy standard (with an estimated yearly energy consumption of 16 kWh/m^2/year). An early workshop in cooperation with the ZEB Centre helped to create a shared understanding of the ZEB aims and commitment, and a confidence among the partners that the balance between zero energy and GHG emission related to operational energy ambitions were realistic. The project management was clear about their expectations and ambitions, and created a goal-oriented, involving and collaborative culture within the project team.

Organization and Management

The project was organized in three main phases. In the first phase (concept design), the client committed the architect and consultant companies to develop three energy standard alternatives (TEK 10, energy class A, zero emission building). After two-third of the calculated time for the concept design (summer 2012), the client decided to reduce the height of the building with one story. The design team had to re-design and re-calculate the three energy alternatives under time pressure. The concept design alternatives were sent to the Ministry of Defence and Stortinget (Norwegian Parliament) in order to get "green light" for proceeding with the planning. This took about two years. The second main phase (detailed design and construction) started in 2014 with the procurement of the contractor and the establishment of the design-build contract. Compared to the rather condensed concept design phase, there were more time available for the detailed design and construction. According to the interviewees from the contractor, this was one of the success criteria for the further development of the project and for the optimization of the technological solutions.

The third phase started with the hand-over to the users in December 2015. The client committed the contractor to a follow-up of the energy aims in a period of two years. The contractor must thus carry out regular measurements and initiate necessary adjustments of the technical installations. If the energy aims are achieved throughout the period, the remaining % of the contract amount will be paid out after two years. There are carried out meetings with the client, contractors and researcher from the ZEB Centre to evaluate the usage of the building and the energy consumption.

Representatives from the users have been involved in the project meetings throughout the design and construction phases. They have, however, not been attending the ZEB-workshops.

The interviewees described the collaboration between the partners as very good, being characterized by trust, transparency and commitment. There was some initial scepticism among the concept design team to the clients' choice of the design-build procurement form. As the work with detailed design developed, it soon became clear that this would be a project driven by the good relations on both company and individual level. The goal-oriented, constructive and motivating management style of the client and the contractor influenced the whole process in a positive way.

Due to the security restrictions at Haakonsvern, the project team were not co-located in a shared office at the building site. However, all main partners were located in Bergen, and regular meetings ensured progress and collaboration. The contractor described particularly one meeting as being especially important for a smooth transition from concept to detailed design solutions. In the beginning of the detailed design, the contractor arranged a general meeting, inviting all project partners and the ZEB researchers. The intention was to ensure a broad commitment to the contractor's optimization of the concept design solutions. Thus, they gave all partners the possibility to interact and to provide the contractor with their opinions and feedback at an early stage.

The project team used BIM-tools (Building Information Modelling) throughout both design and construction. The BIM model became a powerful visual support in design meetings and in the coordination of the various disciplines (clash controls etc.). The contractor did also use BIM as a help for pre-fabricating the steel construction systems, thus minimizing the waste of materials. Simien was used for simulating the energy consumption of the building.

Knowledge
Both the architect and the contractor brought with them some experience from designing and constructing energy friendly buildings. Still, they had not yet designed a ZEB-O building.

The interviewees regarded the connection to the ZEB Centre as positive in many ways. The status as a pilot project helped to consolidate the zero emission ambitions. According to the interviewees, the collaboration with the ZEB experts through workshops and meetings was a crucial factor for transferring ambitions into practical solutions. The interviewees described the meetings with the ZEB researchers as informative, motivating and inspiring.

Both the client and the executing parties agreed upon the positive effect of the follow-up phase. The mapping of the effects of the implemented ZEB solutions provides highly valuable knowledge.

Costs
The costs of the operation of the building was an important topic already in the concept design phase. The client required LCC calculations and estimation of "annual costs" related to all the three energy scenarios. Representatives from facilities management and operation contributed with necessary information in dedicated meetings.

The concept design phase itself was, compared to "traditional" projects, more expensive due to the parallel development of the three energy-scenarios and the participation in the ZEB-workshops. This extra work was however from the beginning a part of the assignment and integrated in the design team's allowance.

The project team estimated the construction of the zero emission solutions to be more cost intensive than the other two alternatives. The client applied for (and got) extra financial support from Enova.
In total, the project costs have lain within the estimated cost frame.

Evaluation
The client had clear ideas about the architectural design and the location of the building: a rectangular building with the sidewall facing south. The interviewees describe the architecture of the building as minimalistic and sober. The implemented technological solutions are standard solutions on a high level. The contribution of the ZEB researchers helped in choosing appropriate solutions such as the ventilation system (demand-controlled ventilation).

Conclusion
Summarizing; we can point at particularly two success criteria in the design and construction process. Firstly, the successful staffing of the project team. Key persons created a positive working culture based on trust, commitment, openness and enthusiasm. Secondly, the client's choice to commit the contractor to a two-year follow-up phase motivated to extra effort and stimulated learning.

Part 2: Early use phase

Participation of the users in the design and construction
In the beginning of the project, the users of the office building mapped and documented their wishes and needs. A representative for the users coordinated this process and the communication between the users and the project team. The users perceived the early concept design phase as frustrating due to the lacking consideration of their demands. They were not involved in the decision to reduce the height of the building with one story. A consequence of this client-initiated design change was the replacement of some of the cell offices by open work spaces. This resulted in a lot of frustration among the users.

The interviewee from the users described the cooperation with the project management later on in the process (the detailed design phase, construction and handover) as positive.

The building in use – evaluation and measures

After the hand-over, the users criticized the temperature (too cold) and the amount of dust in some of the office areas. The temperature was adjusted from the standard 21 degrees to 22,2 degrees, and improved cleaning routines helped minimizing the dust. The outdoor solar shielding did not work properly due to reflections from a roof in the neighbourhood. Therefore, the system had to be complemented with individual indoor daylight shielding solutions. There have also been problems with the sensor-controlled lightning system, which uses more energy than estimated. Improved steering and some individual adjustments have improved the situation. The users have criticized the noise and lack of privacy in the new, open office solutions. The installation of glass walls have helped reducing such acoustic conflicts.

Monitoring and evaluating the energy consumption in the follow-up phase

During 2016 (12 months), delivered energy was 17,6 kWh/m^2, which lies slightly over the energy goal. The project management is, however, confident that the energy goals will be reached without problems. A fine-tuning and better balancing of the technical installations (solar plant, lightning, and ventilation) are among the factors which already proves to secure the achievement of the energy goals.

Conclusion

Summarizing; the lack of involvement in crucial design decisions (less m^2 and more open work spaces) in the early concept design caused a critical attitude towards the new building among the users. They were less concerned about the energy ambitions and related technical solutions, and they were not participating in the ZEB workshops. Still, the temperature being too low and the lighting and sunlight shading not working properly has created much frustration after the handover. The client and the contractor have emphasized a transparent and good communication with the users, and initiated measures and necessary adjustments according to their feedback. All in all, after the first months of handling "childhood diseases" and simply getting used to the new building, most problems are solved and the users seem satisfied with the ZEB solutions.

5. Results and discussion

In this chapter, we discuss the results across the four pilot projects. The discussion is divided into two parts; 1) design and construction and 2) the early use phase. In the latter part, we discuss both the project groups and the users' evaluation of the buildings.

5.1 Design and construction of zero emission buildings

This project was new for everybody, the solutions were partly unknown. Client, Skarpnes

The four pilot projects are addressing various levels of ZEB ambitions, and they are representing different building typologies, scales, project organizations and procurement forms.

Table 3. Building typology and scale

	ZEB House Multikomfort	**Heimdal VGS**	**Skarpnes residential development**	**Visund, Haakonsvern**
Building typology and size	Single-house, show-case. 201.5 m² heated floor area.	High school and sports hall. 26 300 m² heated floor area.	5 single-family residential building. 154.2 m²/house heated floor area.	Office building. 2031 m² heated floor area.

The projects share, however, one particular characteristic; the involved actors are trying to do something not done before. Either by the individual company or in Norway. Harty's five characteristics of a project organization in the construction industry implies the challenges related to the deployment of innovation and implementation of new methods and solutions (Harty, 2005). Compared to a "traditional" building project, to succeed with the ZEB ambitions in the pilots requires a will (and the means) to manage (and accept) the resulting change, risk and innovation needs. This can be regarded as a project in itself – or as a "development project in the building project".

What can we learn from these four pilot projects and the way they organize, manage and carry out their design and construction tasks? What are the most important drivers for success and what are the barriers to be trespassed? In the following, we will discuss the case study findings inspired by the six elements regarded as crucial criteria for successful implementation of change (Moland and Trygstad, 2006, and Moen and Moland, 2010)[14].

Purpose and need

The purpose of the ZEB-ambition and related needs for change should be clear and understood before formulating the goals and measures of the "development project". Was this the case in the four pilot projects?

[14] See page 16, chapter 2.1 (section about elements in dynamic development processes).

Table 4. Motivation

	ZEB House Multikomfort	Heimdal VGS	Skarpnes residential development	Visund, Haakonsvern
Motivation of the client	To build a show-case/demonstration house for position/break-through on the Norwegian market.	To build environmental friendly school in Norway.	"The first zero emission dwellings in Norway".	To be a role model as a public clients and a frontrunner in Norway.
Catalyst	Business possibilities and commercial interest. Being a ZEB pilot.	Push from the county level and their aim of 50% reduction of GHG emissions. Being a ZEB pilot.	In accordance with the "green company profile". Being a ZEB pilot.	Push through assignment from authority/ministry level. Being a ZEB pilot.

For many years now, there has been an increasing push from the Norwegian authorities in the form of new regulations and laws for energy efficiency. There has also been much focus in media on climate challenges and the possible consequences of thoughtless energy consumption. This might be the reason why it has not been very difficult to establish legitimacy and create shared understanding of the purpose of ZEB in the pilot projects on a general basis. The clients seem to be motivated by either social mission concerns or commercial interests, or both.

The perceived usefulness of participating in a pilot project seems to have been a powerful driver for both the clients and the executing parties:

> *The experiences from the project are useful, also personally. It is good for the carrier to have this project on the CV. I have never got so many job offers as I did after I was involved in this project.* Client, Multikomfort

> *It is an ambitious project, and unfortunately these types of projects are seldom here in the region of Bergen. It is a nice project to put on a CV.* Executing party, Visund

These interviewees report individual gains, whereas one focuses on the gains for the company:

> *The quality we sought and found are relevant for many projects. Strong validation of choices. We boast about the project when we try to get new ones.* Executing party, Multikomfort

Several interviewees in the pilot projects emphasized their personal engagement for environmental issues. They were extra motivated, doing their best in order to reach the ambitions. They were happy about the possibility to learn and develop new knowledge, and saw positive effects on career, competitiveness and the ability to acquire, design and construct similar projects. Still, it is not obvious that the building owner or the user shares the client's and the Executing parties' sense of purpose and ambition.

> *The main concern of our departments is that we get the offices we need, that we get the systems we need and the concrete solutions. It has not been important for us that the elevator save energy by going up and down, and such things. We see the value. But it has not been very important for us.* User, Visund

Furthermore, the step from ambition to action can be challenging for all building process parties. "Everyone" sometimes feels the weight of the collective responsibility for "doing something" for a more sustainable future. A shared understanding of purpose or need alone does not automatically grant for a willingness or possibility to change (Fig. 9).

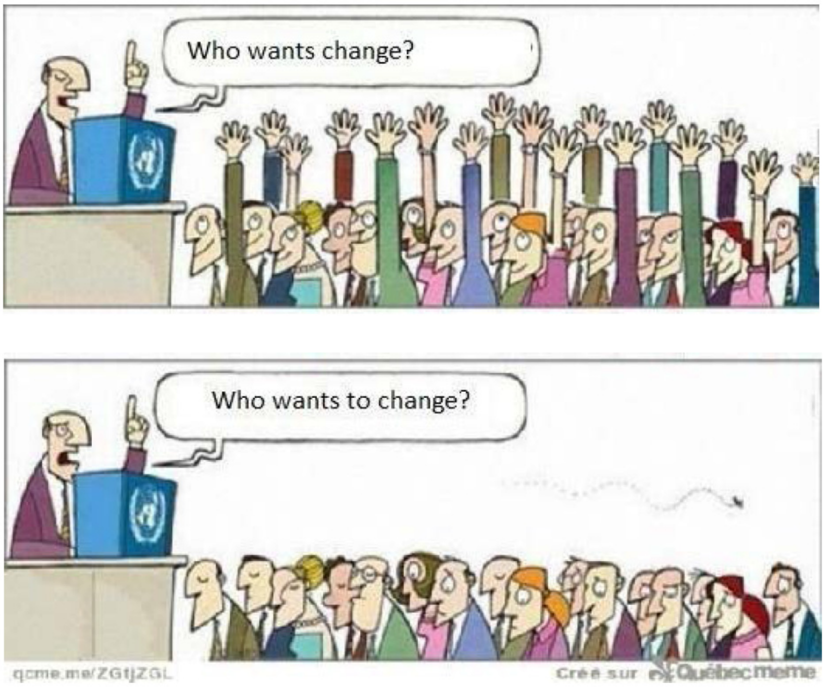

Figure 9. The challenges of change. This cartoon went viral on social media in 2014. Can be downloaded from Quebec meme. The creator of the comic strip is unknown.

Goals

The goals should be both overall and concrete. They must be clear, understandable, and they should be measurable.

Table 5. Goals

	ZEB House Multikomfort	**Heimdal VGS**	**Skarpnes residential development**	**Visund, Haakonsvern**
Level of ZEB and overall goal	ZEB-OM *The building's renewable energy production compensate for greenhouse gas emissions from operational energy use and embodied emissions from materials.*	ZEB-O+20%M *The building's renewable energy production compensate for greenhouse gas emissions from operational energy use and 20% of emissions from materials compared to a reference building.*	ZEB-O *The building's renewable energy production compensate for greenhouse gas emissions from operational energy use.*	ZEB-O÷EQ *The building's renewable energy production compensate for greenhouse gas emissions from operation energy use (excluded the equipment).*

	ZEB House Multikomfort	Heimdal VGS	Skarpnes residential development	Visund, Haakonsvern
Related objectives[15]	Combine a high level of user-comfort with ambitious ZEB-solutions. Produce more energy than used (+House). Reuse of materials, choosing non-toxic materials with low carbon footprint.	Goal on county level: 50% reduction of greenhouse gas emission. Passive-house standard. Use of materials with low carbon footprint.	To build 5 Zero emission houses. Passive-house standard, but upgraded technical solutions (less energy consumption and a higher share of renewable energy).	Energy consumption limited to 16 kWh/m^2/year

In all four pilot projects, the client and their project organizations related their overall energy-efficiency aim to specific levels of zero emission building as defined by the ZEB Centre. They are concrete and measurable on a comprehensive and overall level.

In the Heimdal project, the client and the ZEB experts collaborated on defining the energy goals and related selection criteria. These were communicated to the participating teams in the pre-qualification phases. One of the interviewees perceived the criteria as unclear and too open for interpretation, and recommended more awareness of this in future projects.

Upgrading energy goals

In both Multikomfort and Visund, the client decided to upgrade their original aims together with the decision to appoint these projects to ZEB pilots.

In the Visund project, the client initially wanted an energy class A building. ZEB Centre arranged a workshop with the client and the design team in the early design phase. Here they established a shared understanding of the ZEB aims and a certainty that they were achievable. Additionally, the concrete energy goals were formally included in the assignment of the contractor.

> *We never thought that we would go so far in this project, we thought that we would go for energy class A (...) But then it turned. I believe that the "drive" that came into the project with ZEB and the workshop contributed to this. (...) The workshop pushed the ambitions, and we defined clear goals for the alternatives.* Executing party

In Multikomfort, the client upgraded the ambition from ZEB-O to ZEB-OM, thus including a strong focus on choosing appropriate materials.

Downsizing energy goals

In Skarpnes, they had to down-size their aim by reducing the planned number of residential buildings. The reason for this was a lack of push from the local market. The ZEB-O houses cost more than an average house in the area. The client succeeded to sell and construct five houses. All buyers were from the Oslo area. The project team designed and constructed the remaining 12 residential buildings according to the TEK10 standard.

[15] Here: A "translation" of the ZEB-ambitions/ZEB definition levels into measurable and project specific goals.

A negotiation between different goals

The clients are formulating a number of requirements in a program or brief. The ZEB goals are not the only ones to be addressed by the executing parties. They must also develop solutions, which address goals of economy, functionality, user comfort and more.

Sometimes, these goals are conflicting, enhancing the need for negotiations and compromises. In the Heimdal project, the energy aims were challenged several times in the design phase. A reason for this might be found in the pragmatic need for balancing high-energy ambitions with the aim of designing a well-working school building. One of the interviewees missed a stronger focus on viewing energy ambitions together with issues of use. The client had previously experienced that:

> *(...) complicated solutions often do not work in practice. An overall aim for Heimdal VGS was to focus on robustness regarding operation and maintenance."* Furthermore, that *"(...) every kWh cannot always have the first priority, if it affect functionality and usability negatively.* Client, Heimdal

Several parameters were changed throughout the process.

> *Two changes put the ZEB ambitions under great pressure: the ventilation solution and the increasing size of the sports hall. We got difficulties finding good solutions addressing the energy aims.* Executing party, Heimdal

In the Multikomfort project, the project organization focused on potentially conflicting goals already at the beginning of the project. The project group made the intention of harmonizing these goals into integrated solutions to an overall aim of the project: to combine architectural quality and a high level of user-comfort with ambitious ZEB-solutions. It has been challenging to find a good balance between the relevant parameters, but the team succeeded.

Commitment and ownership

Commitment is about creating an acceptance among the actors of the goals and the related "development project in the building project".

Table 6. Commitment and ownership

	ZEB House Multikomfort	**Heimdal VGS**	**Skarpnes residential development**	**Visund, Haakonsvern**
Owner of ambition/energy goals	Client (ZEB-partner)	Client (ZEB-partner)	Client (ZEB-partner)	Client (ZEB-partner)
Phase of introduction/ implementation	In the ongoing stage of concept development. Upgraded ambition included focus on materials. Required redesign.	Phase one in the prequalification.	Strategic definition phase ("Reguleringsfasen")	Concept development of three alternatives (TEK10, energy-level A, zero emission). Detailed design and construction of the zero emission alternative.

The role and power of the initiator

The client was the one who initiated these "development projects" and the implementation of ZEB ambitions in each project. They regarded the appointed building projects as good arenas for knowledge development, testing and learning. All four clients are partners of the ZEB Centre.

The fact that the client is the one who formally initiated the ZEB ambition in each projects (and not one of the executing parties), gives an additional push.

> *One of my important messages in the company is to avoid a focus on the price only. We want to offer something else: experience and knowledge above average is important. Our customers are contractors and builders. They will feel reassured when following someone who has already gone ahead on the trail.* Client, Multikomfort

Creating commitment by visibility

A spin-off of being a pilot project in the ZEB Centre, is the visibility this gives the project, both in research environments, in the industry and in mass media.

> *At some point of time, as they went to the mass media with it, the client had committed themselves to succeed. The project manager pinpointed repeatedly that we have laid our heads on the block and committed ourselves to deliver this project.* Executing party, Visund

Creating commitment by competition

> *We went through the ambitions in advance, and the building design manager held an engaging session when we started. He explained that here we had the possibility to create something entirely new, something never done before in Bergen. I believe that lit a spark.* Executing party, at the beginning of the detailed design phase, Visund

The contractor was aware of the power of competitive situations, such as described in the quotation above or given by the internal, friendly competition between departments.

Creating commitment by early introduction

Common for all four projects is the early introduction of the ZEB-goals in the building process. This gave the client time to create ownership and commitment among the executing parties before they had come too far with the design process. The ZEB-goals could thus be perceived as a part of the mission instead of something coming in addition to the mission.

Creating commitment across construction and operation

In three of the cases (Heimdal, Visund and Multikomfort) the client is also the owner (or a part of the owners organization) of the completed building.

In the Heimdal project, the client will be responsible for facilities management, operation and maintenance of the building. For them, it is essential to ensure usability and functionality, in order to avoid cost intensive adjustments and rebuild measures. They will therefore commit the contractor to sign an EPC (energy performance contract). This means that the contractor will be responsible for operating the technical facilities the first five years after completion. If the energy use exceeds the goals agreed upon in the contract, the contractor must take a part of the resulting cost.

In the Visund project, the project organization has applied a similar principle. Here, the contractor will get the last 4% of the total payment two years after completion. In this two-year period, he must document that the need for delivered energy proves is maximum 20% higher than calculated. The contractor is logging the buildings' energy production and consumption on a monthly basis. The contractor, client and ZEB-experts sometimes meet to analyze and evaluate the numbers. If there are problems, measures are undertaken. According to the contractor of the Visund project:

> *The measurements indicate that we will achieve the energy aim. This is reassuring. The contract allows a deviation of 20% on delivered energy, which is marginal in such a small project. Some call it a carrot, I call it a stick. But it is ok.* Executing party, Visund

> *Perhaps this makes us go into this with extra effort.* Executing party, Visund

In both the Visund and the Heimdal project, the clients thus committed their contractors to take part of the responsibility related to the energy performance of the building after hand-over.

<u>Formal versus informal commitment</u>
In all projects the energy goals are formulated (more or less precisely) in contracts or in the executing parties' assignment. This ensures a formal commitment to the goals. However, as we see above, informal measures of commitment are equally important.

Collaboration and involvement
It is important to build good teams and engage the expertise needed to achieve the goals and carry out the related measures.

Table 7. Collaboration and involvement

	ZEB House Multikomfort	**Heimdal VGS**	**Skarpnes residential development**	**Visund, Haakonsvern**
Project delivery method	Partnering	Design-build with prequalification and partnership contract	Design-build	Design-build

<u>Procurement forms and collaboration</u>
In all pilot projects, the interviewees emphasized the importance of collaboration as a means to achieve zero emission building.

In the Heimdal project, the client tried out a new way (for them) of committing the project actors. They wanted a process allowing a holistic and multidisciplinary focus and a tight collaboration between client, user and Executing parties.

The client has used design-build as an integrated procurement form. Based on the project definitions and aims developed together with the ZEB Centre, they initiated a two-step pre-qualification ("two-step competitive dialogue"). The purpose was to open up for a creative and competitive development of as mature concepts as possible, before contracting the project team. A dialogue with the client was a crucial element in this.

> *We regarded a "normal" competition as insufficient, because the prices are estimated based on an immature proposal.* Client, Heimdal

After the pre-qualification, the client and the executing parties signed a partnership contract. In the following collaborative design phase, the user became an increasingly important part.

In both the Visund and the Skarpnes project, the clients went for a design-build contract. In Skarpnes, this was an obvious choice for the client, who was also the contractor. The interviewees emphasized the well working collaboration in the design process between those with theoretical knowledge and the ones with practical experience from construction. Still, the collaboration between the contractor and some of the external executing parties could have been even better.

> *It would have been very interesting to work more interdisciplinary.* Executing party, Skarpnes.

In Visund, the consultants who had been responsible for developing the concept design, were initially rather sceptical to this choice. Based on previous experiences with this procurement form, they were concerned about the ability of the contractor to procure parties qualified to address the high energy ambitions. This did, however, not become a problem (on the contrary).

> *It is easy to believe that when there are two design teams[16], there will be frictions; you want to show how good you are (...). But the collaboration was good. After a while we forgot where we came from and which roles we had. We were focused on this being something we wanted to succeed with. (...) The typical challenge in design-build contracts, the nagging about money and additional payment, occurred very seldom.* Executing part, Visund

The Multikomfort project was organized differently. The clients are wholesalers of building and plumbing materials in Norway, using this residential house as a showcase. They also took the role as consultants. They involved an architect who was also a ZEB partner. They considered a partnering contract as appropriate, enabling the project's actors to collaborate on the development of new and unknown solutions. Such a contract does, however, require equal trust. Interestingly, some of the interviewees see the design-build contract as unsuitable for these kind of projects. High (and unsure) prices will increase the perceived risk and the cost of the project.

The interviewees in all pilots felt that there was an overall good collaboration between the involved parties. They pointed on several factors, which have positively affected the collaboration between the actors in their projects.

Openness and trust:

> *You cannot only focus on your own interests and the profitability. You must focus on collaboration, and you must be willing to play with open cards.* Client, Multikomfort

Good relations:

> *I have never attended a project where it has been such a good chemistry and collaboration between everybody. (...) People and chemistry play an important role.* Client, Visund

Good management:

> *The project manager was good at avoiding conflicts, he got things solved.* Executing part, Visund

Building good teams:

> *It has been a very good mix of the young, aspiring and groundbreaking, and the older and more experienced with a healthy critical view on various things.* Executing party, Visund

[16] The one design team was hired by the client, with responsibility for the conceptual design and for following up the client's interests in the detailed design phase and construction. The other the design team was involved by the contractor, with responsibility for the detailed design.

Involvement
In the Multikomfort project, the ambitious goals did not only challenge the competence of the design team, but also the skills of the workers on the building site. Although the complexity of the building itself is low, the processes on the building site has been complicated. The site workers had no experience with zero emission building. The interviewees learned that in such building projects with a high degree of innovation and development, it is extra important to focus on good communication between the design team and the executing part on the building site. There was often a need to adjust and improve solutions directly on the site. This required an understanding of the intentions behind the details. Another lesson was that it would have been better to identify and solve some of the problems earlier in the process, and not on the building site. Early involvement of the builder in the development of the solutions would have been helpful.

In the Visund project and early in the detailed design phase, the contractor invited his people, the design team, the client and some of the ZEB-experts to a joint meeting. They went through all the technical solutions and the most important components, thus inviting the other project parties to take part in (and influence on) their thinking behind adjustments and further optimization.

> *We have delivered a system which in many points is better than what was described in the conceptual design phase. Sometimes we have not chosen exactly the same, but the functionality is the same. But we are open about this. Instead of working alone with this until it is finished and then raise a lot of discussions about why we did it this way or another, we arranged a joint meeting in the beginning of February last year. Here we could harmonize and establish an agreement. If there were something we could not agree upon, we got a homework to check it out. And we checked it out, instead of discussing things after we had built them.* Executing party, Visund

The Visund-contractor also invited the suppliers to explain their products to the designers and site workers. The building design manager explains the following from constructing the facade with sufficient air tightness:

> *The suppliers tell us about their products instead of delivering a box with tape. They show us how to do it and why. This motivates our experienced people more than we do by just forwarding the message that 'you must do this'.* Executing party, Visund

Resources
Do the executing parties have the extra resources they need to succeed?

Table 8. Resources

	ZEB House Multikomfort	**Heimdal VGS**	**Skarpnes residential development**	**Visund, Haakonsvern**
First time for the initiator?	St Gobain international has a Multicomfort-program. For the Norwegian stakeholders, it is first time.	Yes. Both regarding the technical solutions and the chosen procurement process.	Yes	Yes

	ZEB House Multikomfort	Heimdal VGS	Skarpnes residential development	Visund, Haakonsvern
Previous ZEB competence in the team	No, not with ZEB-OM. First time for the architect and for the builders and site workers. The client is a supplier and wholesaler of building materials. Useful experience on (and access to) materials.	Yes, on company level (not necessarily individual level). The CHP solution was new to all parties.	Yes. Passive house level.	Yes, particularly one of the architects and the contractor.
Measures for increasing competence	ZEB-workshops.	ZEB-workshops and excursions.	ZEB workshops and excursions. The client attended courses in Sweden and Switzerland (solar energy solutions).	ZEB-workshops.
Financial support	The executing parties were paid by hours (not fixed sum).	It has been developed a proposal for Enova support (the CHP solutions). Important for reducing risk.	Yes (solar energy solutions).	The design team got some extra money for developing three alternatives in the conceptual design phase, and for participating in ZEB-workshops. Enova support important for choosing the most ambitious alternative (ZEB-0÷EQ).
Time	More time necessary in both design and construction.	Two-step pre-qualification instead of one-step. The elements of unknown solutions (CHP machine) and the strong focus materials required time.	More time consuming to build than estimated.	The decision process on authority level set the premises for the deadlines. Too little time for the conceptual design stage (due to a big change), enough time for the detailed design phase and construction.
Tools	BIM. LCA (using excel based GHG emissions calculation tool developed at the ZEB center, which is based on specific EPD data or generic data from ecoinvent database), Simien, Rhino.	LCA (using excel based GHG emissions calculation tool developed at the ZEB center, which is based on specific EPD data or generic data from ecoinvent database). BIM.		BIM. Simulation tools (Simien and more).

Competence, learning processes and the importance of ZEB

Generally, the involved in the four pilot projects did not have previous experience from design and construction of buildings according to the selected level of ZEB ambition in their specific project. At least not at an individual level.

> *Even though the personal level of competence was not good enough in the beginning, the total level of competence in the company was sufficient enough for Heimdal VGS. You have to communicate internally and look at relevant projects, both theoretical and practical examples. The Heimdal process has contributed to raising the individual level of competence.* Executing party, Heimdal

In the Multikomfort project, the clients' knowledge and overview on both material technology, availability and good suppliers, as well as plumbing technology, was highly useful in order to address the high ambitions on choosing (or reusing) non-toxic materials with low carbon footprint. In the Visund project, the building design manager had previous experience from managing projects with energy-efficiency ambitions. This gave him a basis for avoiding some pitfalls, and for designing a good process and arenas for communication and development (a good management of the "development project in the building project"). In all pilot projects, the interviewees pointed at the need to learn and gain new knowledge throughout the building process.

> *We have matured throughout the process. What was regarded as "hairy" aims at the beginning, required more competence among all involved. The process has also lifted the competence level of other actors in the industry.* Client, Heimdal

> *The main principle is to use existing solutions for new results. This should not be rocket science, but it requires that all participate and contribute. It is a learning process for all involved parties.* Executing part, Multikomfort

> *We want to be regarded as a company with a green profile, and Skarpnes was an opportunity to test out new solutions.* Client, Skarpnes

Being an appointed pilot project of the ZEB Centre, gave all four building projects a unique access to expertise and support.

> *This has been a pioneer work, where we have been dependent on the collaboration with research environments.* Client, Multikomfort

Multikomfort, Visund and Heimdal carried out workshops and meetings with the ZEB Centre, particularly at the early stages of the building process. The ZEB researchers played an important role in defining, formulating and explaining the energy goals, in finding and securing good solutions, and in helping developing systems for evaluating the effects and functionality of the technical solutions. The mostly used arena for involving the ZEB people was the workshops.

> *We prepared solutions in small work groups, which then was evaluated and viewed as a totality in bigger fora. Before each workshop, you had to develop solutions and show the consequences for the energy use, the technical systems and the greenhouse gas emission. You had to develop scenarios.* Client, Multikomfort

> *These were good processes, in which it was very interesting to participate, particularly because of the interdisciplinary composition of the groups who attended the workshops.* Executing party, Visund

The interviewees describe the workshops as motivating, inspiring and educational.

Personal engagement

Individual ZEB-enthusiasts with great personal engagement characterize all four projects, both on the client side, and on the side of the executing parties. When these enthusiasts also hold key positions in the project organizations, such as management positions, they are extra powerful agents of change and development. They played an important role in promoting the ZEB ambitions and pushing through the necessary decisions.

Time

In the Multikomfort project, they experienced that particularly the construction phase was more time consuming than estimated. The team was under pressure to deliver on time. On the other hand, the client pointed out:

> *You have to use the time well in the conceptual design phase, and you must be willing to accept the related costs.* Client, Multikomfort

Also in Heimdal, some of the interviewees perceived the decision processes related to the choice of materials and technical solutions as slow. It took extra time to understand the aim and related consequences (compared to "normal projects"), particularly in the early stage.

In the Visund project, a big change late in the conceptual design phase put a lot of pressure on the design team. Due to the decision processes on the ministry level, the client could not change the deadline. This left too little time for creating ownership among the users to the related consequences (from cell offices to open landscapes). This probably affected the user acceptance negatively (see discussion in part two). In the detailed design, they had not the additional pressure of delivering to the ministry within a specific time frame. The interviewees perceived that they had enough time.

> *I believe that was one of the criteria for success. To have enough time to go through all challenges and all the things which have to be planned and solved.* Executing party, Visund

Economy

For all clients, the pilot projects have generated extra costs compared to a "traditional" building project. Related either to the design and construction processes themselves (more meetings, more planning time), or to the technical installations, constructive solutions or building materials (or both). It has been difficult to obtain detailed figures about construction costs (and additional costs related to achieving the zero emission balance). The most specific numbers we have are from the Skarpnes project, where the client estimated the price of the ZEB houses to be approximately 8.-900.000 NOK higher than for a comparable dwelling built according to current building standard (TEK10), located in the same area.

Two of the pilots got extra support through money from Enova. Although a return of investment, or even profitability, is given through the energy efficient solutions (from using to producing energy), the building process requires a mobilization of financial resources. In the Skarpnes project, the extra costs required buyers who were willing to pay more.

Awareness that pilot projects cannot be profitable (Heimdal). The same in Multikomfort:

> *This is not an example of a cost efficient construction. If we had built this house one more time, everything would be cheaper, more streamlined.* Client, Multikomfort

The client and the building owner can expect a return of investment. But what about the executing parties, such as the architects, consultants and the contractors? Did they get extra resources to do the development job, which adds more workload compared to a "normal" project? In the Visund project, the design team got extra financial resources to develop the three alternatives in the conceptual design phase. In the Heimdal project, they integrated a part of the development project in the two-step prequalification, where all participating parties were paid for their work.

Tools

In the Visund project, the interviewees pinpointed BIM as important for the interdisciplinary coordination, decision-making and visualization. Separate software was used for energy and daylight simulations. In Heimdal and Multikomfort, also LCA-tool (an excel based tool developed at ZEN centre for GHG emission calculation based on mainly product specific EPD data or generic data from Ecoinvent database) were helpful.

Follow-up

In many building projects, there is a shift of actors and responsibilities after the hand-over to the user. This sometimes makes it challenging to "close the loop" and "feed back" experiences to the project organization on whether they achieved the energy aims. The lack of such feedback loops, might hinder learning and improvement.

As we have seen, in three of the cases (Heimdal, Visund and Multikomfort) the client is also the owner (or a part of the owners organization) of the building. In addition to the element of creating ownership and commitment to the result, this gave the project organizations particular possibilities when it comes to evaluation and learning.

In the Visund project, all interviewees collectively emphasized the value of such evaluations of the chosen energy solutions after hand-over. They regard the possibility to see how the designed and built solutions actually work out as highly useful. Also in Heimdal, the client intend to measure and evaluate the operation and use of the building after its completion in 2017. One of the interviewees points on the high risk of building something not tested out before, and emphasizes the resulting need for evaluation and learning. How do the new and innovative solutions work out in the everyday use of the building?

Summarizing reflections

We will here summarize the main findings related to the six elements, which we may regard both as drivers of change or as characteristics of the development processes in the four ZEB pilots.

- *The purpose, need and legitimacy of the change.* In all four pilot projects, the project participants in design and construction seemed to have a shared understanding and acceptance of the purpose and need for ZEB. The actors saw the possibility to learn and gain new knowledge as highly useful for their own carrier/company and competitiveness.
- *Goals.* The ZEB-definitions as developed by the ZEB Centre worked as a guidance on overall level. In all projects, they chose a ZEB goal, which was placed one step higher up on the ambition ladder, viewed from their base of experience and knowledge. The ZEB Centre played an important role in pushing the ambition level. Looking at the projects as a totality, the actors had to balance the goals of energy efficiency with goals related to e.g. functionality, user-comfort, and economy. This was partly challenging, and sometimes required a negotiation between the goals. The projects handled this differently. They partly modified the ZEB-goals, partly they tried to develop solutions, which unified the seemingly conflicting parameters, and partly they prioritized the ZEB goals, accepting possible negative effects elsewhere.

- *Commitment and ownership.* A highly committed and motivated client was the initiator of the ambition in all projects, thus creating a strong push by being the appointing (and paying) party. The ZEB goals were a part of the assignment of the executing parties. All clients (and several of the executing parties) are partners in the ZEB Centre, which in itself indicate an interest in "green building". The visibility of being a ZEB pilot, motivating managers and early introduction of the ZEB-ambitions, were further drivers of commitment. In addition, in three of the cases, the clients were also the owners of the building, thus creating a continuity of commitment – not only to the process, but also to the resulting building. In two of the projects, the clients formally committed the contractor to share the responsibility for the energy-solutions after hand-over to the users.
- *Collaboration and involvement.* In all four projects, there was a focus on enabling well-working and interdisciplinary collaboration as important means for zero emission building. The projects used different procurements forms and delivery methods, mostly based on previous experiences or a perception of what would be the right choice in projects with a higher share of uncertainty compared to "traditional" projects. The pilots indicate that there is no unique procurement form, contract or execution model for ZEB projects, as long as such formal measures and contracts not in themselves hinder communication and collaboration between the parties. In all projects, the actors pointed on several informal factors being crucial for the collaboration, such as trust, openness, good leadership, good relations and chemistry between people. This harmonizes with findings from research on collaboration. The "human factor" and committing the "right people in the right roles at the right time" is important. Good formal measures might thus not be enough if there is no basic trust or willingness to collaborate among the parties. Another important point indicated by the pilots is the importance of involving the construction people (builders and site workers) in the development and design processes.
- *Resources.* The actors in the pilots were aware of the challenges given by their lack of experience. They regarded the extra push through the expertise and support of the researchers in the ZEB Centre as particularly important. In all projects, they made the experience that uncertainty and the need to understand the goals and develop unknown solutions is both time and cost intensive. In some of the cases, the client made extra resources available from the beginning. The economical support from Enova was important for the projects applying for such. Personal engagement and the passion of some key persons really believing in the purpose and goals, was positively affecting decisions and the attitude and stamina of the other actors.
- *Follow-up.* In one of the cases, the actors have already experienced the positive learning effects of the possibility to evaluate and measure the effects of the developed ZEB solutions.

Overall, the actors involved in the design and construction of the ZEB pilots seem to, or have succeeded with their "development project within the building projects".

We will wrap up this section with some reflections on two other issues of development projects related to the implementation of change and related innovation measures.

<u>Selecting suitable building projects as arenas for pilot studies</u>
We have analyzed and discussed the experiences of the building process actors in the pilot projects, and identified important process-related success criteria for achieving ZEB goals. We have, however, not discussed the suitability of each of the building projects as testing arenas for the respective goals and innovation ambitions. Three factors seem particularly important; the complexity of the building project, the competence of the people involved, and the ZEB-goal with related ambitions of (or need for) innovation (Fig. 10).

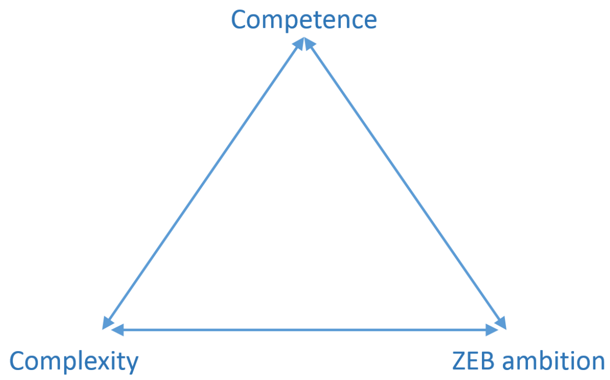

Figure 10. Critical relations influencing the level of difficulty of the "development project in the building project".

The actors in the four pilot projects have been or are facing various levels of difficulties in their efforts of achieving the ZEB goals (Table 9). In the Heimdal project, one of the executing parties reflected on whether it is a good idea to use such a complex project as a pilot project. He saw a risk for failure and cost-intensive changes and improvements. Out of the four pilot projects, the Heimdal project seems to be the most challenging one, based on the combination of high project complexity and ambitious ZEB goals and solutions.

The higher the level of difficulty of the development project, the higher the risk (and the potential benefits), the more important it will be to focus on the six criteria for successful change.

Table 9. Overview of the ZEB goals, the project complexity and the ambition of/need for innovation.

	ZEB House Multikomfort	**Heimdal VGS**	**Skarpnes residential development**	**Visund, Haakonsvern**
ZEB goal	ZEB-OM	ZEB-O+20%M	ZEB-O	ZEB-O÷EQ
Complexity of the building	Low	High	Low	Low
Ambition of/need for innovation	Develop new solutions based on existing knowledge.	Develop new solutions based on the unknown.	Develop new solutions based on existing knowledge.	Optimizing existing solutions
Examples	Solutions combining high user comfort with ambitious energy goals (+ energy and environmental friendly materials).	Combined heat and power (CHP) unit, fueled by locally produced bio-gas.	New system for construction and production of wall elements	*"It is a passive house with a solar plant on the roof. There are no 'special-special' solutions."*

<u>Societal consequences (repercussion)</u>

Pilot buildings can be well working instruments for bringing new knowledge to the building market.[17] The actors involved in the four ZEB pilots have been through an extensive learning process. In the Skarpnes project, the client described pilot projects as generally not profitable, but as important for developing new knowledge. The project actors will use what they have learned in future projects. In all the case studies, the project teams and owners have talked about how the building projects create attention

[17] See Chapter 2, p.15.

outside the ZEB Centre. They are asked to present their experiences from zero emission building on various arenas, and the pilot projects have caught attention in mass media.

In the pilot case of Multikomfort, the building owners, who are also construction material suppliers, say that the pilot building has contributed to put a pressure on the construction material *producers* to use LCA results through EPDs to improve and document the environmental performance of their products. There has been a constant increase in the number of EPDs (Environmental Product Declaration) in Norway the last years. The building owners think that their demand for EPDs may have led to the development of some of these.

> *Pilot projects such as this one affects the producers, especially when the client is a wholesaler of products. When the producers realize that they must have an EPD, the demand for this will affect the whole industry. Then it starts rolling. A push from our company means a lot.* Client, Multikomfort

The same is commented on in the Heimdal pilot case:

> *Many building material producers have been asked about EPDs during the project phase, and this will probably create more awareness of this in the sector.* Executing party, Heimdal

5.2 Project groups' evaluation of the buildings

We have been interested in the project groups' evaluation of the buildings to look for differences between the project groups' and the users' experiences of the building. If there are huge deviations, the building process might not have taken the users' perspective enough into consideration. Are the buildings understood in the same way by the users and by the project group? In addition, people planning zero emission buildings will be interested in the project groups' experiences with different architectural and technical solutions. The process reveals how the project groups tested different solutions along the way.

Here is the evaluation of the buildings by the project groups:

Architecture and construction

Table 10. The project group's evaluation of the architecture and construction methods

	ZEB House Multikomfort	**Heimdal VGS**	**Skarpnes residential development**	**Visund, Haakonsvern**
Evaluation of the architecture and construction methods	The project team is satisfied with the architecture, they think it is elegant and functional. The architect is satisfied on the basis of "off the shelf"-concept. Visitors often think the building is strange from outside, but homely from the inside. Challenge: detailed projecting of technical solutions were not conducted in the design phase and therefore took time in the construction phase. The project team missed input from the executing part on technical solutions. Double passive house walls worked well. ZEB-concept decisive for the choice of materials.	Project owners are happy with the results so far. Executives are a bit more critical, saying that the architectural result could have been better, but also adds that it is perfectly normal to think so. The solar cell elements bind the architectural expression. ZEB-concept decisive for the choice of materials.	The project group is satisfied with the architecture. The architect notes that the façades have signs of previously scheduled solar collectors that were not used. Roof pitch was chosen because of the solar cells. The zero energy concept influenced also the orientation and the size of the houses. The construction of the walls were simplified along the way. ZEB-concept decisive for the choice of materials.	The project team thinks it is an unpretentious building. It has a sober and precise expression. The architect's suggestions for more variations in the expression was declined due to economy. White and light grey interior colours are chosen to decrease the need of lighting. ZEB-concept decisive for the choice of materials.

Architectural expression

Across the four pilot cases, the project owners are often satisfied with the architecture, however the architects /executing party are self-critical. At Multikomfort, the architect is satisfied based on the "off-the shelf"-concept. The interviews at Visund also reveal that the architects' suggestions for change and variation have been rejected because of economy. Changing the orientation of the building at Visund might have had positive effects on the work environment through more daylight and less irradiance, according to the executing party. Nevertheless, it was neither time nor finances to consider a different orientation than what the building owner originally required. The architect of the Skarpnes dwellings believes it would have affected the design of the houses positively if the architect office had been involved earlier in the process.

The two housing projects, Multikomfort and Skarpnes, are both influenced by the aspiration to make the dwellings homely. Multikomfort is not experienced as homely from the outside, and visitors often find it strange. However, from the inside visitors often find it "surprisingly homely". The dwellings at Skarpnes are more traditional in their expression, and it is said that nearby housing from 1700 was used as inspiration. At Multikomfort, the architectural choices were influenced by the idea that most people should be able to live there, and despite the passive house concept, the windows should be possible to open. The project should not ignore the living culture, although the dwellings were innovative. The executing party of Multikomfort also pointed out that the pilot project has an important symbolic effect for the concept of single-unit dwellings. Detached housing has been seen as an environmental sinner;

however, the pilot project shows that it is possible to build a single-unit dwelling with good conscience. The building could theoretically even function independent of the power grid.

Figure 11. Exterior and interior Multikomfort (photo: Optimera and Brødrene Dahl)

Architecture tied up by the zero emission concept

What the projects also have in common, is the way that the zero emission concept is described as binding for the architecture. In what ways?

Having solar cells (photovoltaic elements) on the facade/ roof tie up the architectural expression. This is pointed out both among interviewees for Heimdal VGS and Skarpnes. Especially the solar cells elements affected the design, orientation and location of the dwellings at Skarpnes. The dwellings were oriented to optimize the radiant-flux density. This created some limitations in the design, the executing party said. If the building design with solar elements is rejected late in the planning phase, the old solar assumptions in the architectural expression remain. At Skarpnes, the executing party think it is still visible that the dwellings were designed for solar collectors, even if solar collectors were not used in the end, only solar cells.

Figure 12. Skarpnes dwellings, solar cells (photo: SINTEF Byggforsk). Visund solar cells (photo: Bjarte Hårklau, Veidekke*).*

For Heimdal VGS the architectural design had to be flexible in order to cover future user needs without major reconstructions. However, the spatial efficiency was significant to obtain the zero emission ambition. The architectural solutions were very different in the sketch projects delivered in phase 2 (3 teams). In the winning project, the architectural and structural choices were assessed in several rounds calculating the carbon footprint. The choice of materials was dependent on these calculations. Concrete was chosen over wood because several layers with gypsum boards underneath the roof was necessary to meet the official requirements for fire and acoustics. This eliminated the carbon footprint reduction advantage of wood.

The executing party of Skarpnes says that the ZEB concept strongly influenced the architecture. The calculation of emissions led to a limitation of the size of the houses. The interviewees did not only design the zero emission dwellings at Skarpens, but also the TEK10 standard houses. They say that the differences between the houses are small. However, for the TEK10 houses they had more freedom in choosing building size, window size, fireplace and chimney, orientation and location on the site. The zero emission concept led to stricter guidelines in order to achieve the right energy accounts. At Multikomfort there has been a stronger focus on choosing the right materials and finding the environmental balance than in other projects the executing party and building owners have been part of.

Construction methods and innovation

The pilot cases also show that the construction methods typically changed along the way, as the zero emission innovations required testing different solutions. For example, the construction of the walls in the Skarpens dwellings was complicated in the beginning. It turned out to be too advanced and time consuming, and the construction method was changed to simplify the building process and decrease the time spent on building walls. At Multikomfort, double passive house walls worked well.

Another challenge was the need for practical input to the construction methods from the contractors. At Multikomfort, the project owners/ consultants missed input from the contractors on the construction methods. An example was the use of laminated wood constructions. The work was done inside a building tent for weather protection (especially important for airtight constructions). However, laminated wood became heavy and unhandy within the tent, and this prolonged the building process. The contractors did not see this coming. On the other hand, the contractors wanted better planning of construction details in the project. The innovation and the environmental focus meant that they did not have all the answers before they started; they had to try methods they were not familiar with. Often, the solutions to construction details appeared during the process. The contractor wished the solutions were sketched and planned in advance:

> *To focus on thoroughly projected solutions before starting to build, will save time. "We will do it when we get there" - is not a good solution.* Executing party, Multikomfort

Better planning of details where it is possible is an advantage. However, the pilot projects demonstrate that is not always possible to design all construction details in an innovation project. The innovation sometime required time consuming and expensive failures and changes. In addition, the executing party at Multikomfort say that the focus on zero emission may lead to solutions that are more expensive because using recycled materials often are more time consuming. An example from the Multikomfort-project is the stone walls:

> *The environmental focus may imply more labour-intensive solutions, and the solutions are therefore more expensive.* Executing party, Multikomfort

Summarizing reflections

To summarize; the project teams are satisfied but self-critical to the architectural design. The construction methods typically changed along the way, as the zero emission innovations required testing different solutions. There are also examples of the ZEB concept leading to construction methods being more time consuming than traditional methods. The interviewees believe that the architecture and orientation are strongly influenced by the zero emission concept. This especially concerns how the *solar cell elements* affect the design, and how the zero emission focus affects *the size* of the buildings, *and the materials* chosen. The intentions are in other words powerfully environmental. The question is if the users see the architecture that way, and if they act on it.

Technical solutions

Table 11. The project group's evaluation of the technical solutions

	ZEB House Multikomfort	Heimdal VGS	Skarpnes residential development	Visund, Haakonsvern
Evaluation of technical solutions	The project team is satisfied with the technical solutions. Solar cells, solar collectors and heat pumps, grey water heat recovery works well. The owners miss full testing of operation, is not possible since the house is a show case. The technology is well hidden, and it does not appear as a "smart house", but rather homely.	Innovative solutions: biogas based CHP machine. The executive actors are only partly satisfied with the biogas solution, since it will not be profitable in competition with district heating. This was chosen to obtain the zero emission concept. The building owner changed the ventilation solutions to traditional solutions in smaller decentralized units, due to negative experiences with other types. This created challenges for the ZEB ambition, and the executing parties are critical.	The project team is satisfied with the technical solutions. The houses have solar cells. Solar collector and grey water heat recovery were considered, however this was not profitable. Geothermal heat pump was installed for domestic hot water and floor heating. Fan coil unit as a supplement is installed in the living room.	The project team is satisfied with the technical solutions. In principle, this is a passive house with solar cells on the roof. Demand controlled (heating and cooling by air), radiators, lighting via motion sensors. The building is connected to district heating at Visund, and in principle a remote cooling (free cooling).

The technical solutions include the systems providing heat (cooling), ventilation and light. Common for all the pilot projects is the thorough calculations of all options in order to find the most suitable solutions when it came to environmental assets and financial costs. No solution was chosen due to tradition or diffusion.

<u>*Energy supply*</u>
At Multikomfort, the energy supply includes solar cells, solar collectors and heat pumps. And the project group has good experience with the solutions. Also the grey water heat recovery system worked well during testing. Since the house is a show case for the building owners' firms and their products, no one is living in the house to test the technical solutions in everyday life.

At Heimdal VGS all three teams that delivered proposals in phase 2, arrived at the same conclusion regarding energy supply: A biogas based CHP-machine. They all regarded this as the only possible solution that could meet the building's needs and compensate for the emissions related to operational energy and 20% of emission from material utilization (ZEB-O+20% M). The energy supply solution was changed several times. However, in the interacting phase/ pre project, the winning team went back to biogas based CHP machine and photovoltaics. This happened as a consequence of space increase.

Profitability of heating systems is always a challenge in district heating areas. The executing party is not completely satisfied with the solution, because the majority of the energy will be exported, and they will lose money on the export prices since they do not earn what it costs producing the energy.

The Zero emission dwellings at Skarpnes have external shading devices that are controlled automatically by solar radiation. Solar cells and heat pumps were chosen over solar collectors and greywater heat recovery system due to a cost-benefit analysis. Hot water on Skarpnes is produced through a geothermal heat pump. All dwellings have central heating systems based on one or two convection fans on each floor. Then there is under-floor heating in bathrooms on each floor, for some dwellings, also in hall and washing rooms. Executing party is satisfied with the result, and they are excited about future evaluation. However, one of them says he believes that some households will not reach the aims of energy efficiency.

At Visund, the solar cell installation is so compact and precisely dimensioned that a small area of the roof is idle. During the period from the first concept sketches to construction start, there was developments on the solar installation front. The reduction of the number of floors in the pilot project created some challenges getting enough capacity for solar cells (flat roof instead of inclination). However, the solar installation development was progressing, and the solar elements had enough capacity when the project reached the detailed engineering. The second energy source is a seawater-based heat pump. There have been some discussions along the way about the need for heating sources in addition to heating by air. It was, after input from the consultant side, chosen to use radiators as additional security. The heating pump delivers heat both to the ventilation system and to the radiators. The heating pump delivers local heating to the building, within the system boarders.

> *It's a passive house with a solar energy system on top. It's nothing special - no customized solutions. It is more that we have tightened the screws a bit in all ways. There is nothing extraordinary about this building. It is off the shelf, but it is from the top shelf. And then we sewed this together in a good way. All things work together.* Executing party, Visund

<u>*Ventilation*</u>

In the first proposal for Heimdal VGS, displacement ventilation was used as a basis for the energy calculations. The building owner was sceptical to this. The ventilation system was later changed to traditional ventilation in most areas. Ventilation is currently organized in smaller decentralized systems. The building owner had experience with the operation of smaller ventilation installations, and summarizes that smaller installations are more easily adjusted. The ducts` distances are shorter and system losses can be minimized. The practice from other buildings they operate, shows that it is difficult to adjust large ventilation systems. Simplicity of systems has been a slogan throughout project period. The executing party is not completely satisfied with the ventilation concept. The change had implications for energy demand and the environmental objective. The "O" (zero emission in operation) was hard to reach, according to the executing party. One of them believes that the ventilation system may be too simple and small, which could mean that the building becomes over-ventilated and consume too much energy. This illustrates that there is uncertainty about the choice of ventilation solutions, and that there is a need for evaluation of the building in use to be able to evaluate the choices made.

Balanced ventilation which was chosen for Skarpnes has high recovery (e.g. better quality and more expensive than in the nearby TEK10 houses). One of the interviewees at Visund points to the counselling from ZEB-researchers as important to choose balanced, demand-controlled ventilation with heat recovery via rotary recyclers.

Light
All the projects have lighting via motion sensors, except Skarpnes. This has not been a topic in all interviews, but one can assume that the project teams think it works well since they have not brought it up as a problem. However, the lighting is brought up as an issue in the user evaluation, along with other topics. See later chapters.

Summarizing reflections
To summarize, across all the pilot cases, the project teams' *thorough calculations* of carbon footprint and financial costs are central. The pilot cases show that this has been challenging and has required high competence from involved actors, as well as help from researchers. The selection of energy supply has typically changed many times throughout the planning process.

The pilot cases do not show whether environmental or financial costs trump the decisions. It is an act of balance. However, it seems like the environmental focus in the pilot project has opened up for spending more money on innovative solutions that may be an ideal for others. This probably arises from the nature of being a pilot building. Nevertheless, the best environmental solutions are not selected at every cost. There are clear economic boundaries, and the boundaries are naturally stricter in the public building projects, than in the private firms' show case house (Multikomfort).

Most of the project teams are satisfied with the energy supply, heating and ventilation systems they ended up with. However, Heimdal VGS seems to have had more discussions about what systems to choose, and the executing party is more sceptical to the choices taken. This pilot building is also the only building that is not yet built (by 2016), and the results may be influenced by the building process phase in which the interviews were conducted. When a building is complete, it is easier to settle with the solutions chosen, and more difficult to picture alternative solutions.

The technological ideas are clearly environmental, but not visible in every sense. The ventilation system do not necessarily appear as different from systems in other new buildings. Accordingly, the users do not necessarily understand the environmental profile of the system. However, the solar energy systems, the panels on the roof or on the walls, visualize the zero emission concept to a great extent. The question is whether the users understand the technical systems. Do the users understand the energy efficiency anticipated?

5.3 Early use phase – user experiences, acceptance and negotiations

Only two of the ZEB-pilot buildings were evaluated from the users' point of view; Skarpnes and Visund. Only these projects had been taken into use at the time of the evaluation. The projects are very different; a housing project and an office building, and it is therefore difficult to compare them. Also the experience of the buildings seems to be very different.

Practical domestication

Practical aspects address the actual use of a technology or a building, its' practical workings and how they fit into existing practices (or not) (Godbolt, 2014; Sørensen, 2006). How did the residents and workers take these building into use? What were the frictions in the first phase?

Architecture
The residents at Skarpnes in Arendal are in general satisfied with their dwellings. These dwellings appear to be quality housing and a good zero emission project. Some of them said they would have wanted the living room to be larger, but they are in general happy with the building and the architecture.

At Visund on contrary, the residents are discontented with the open-plan office, and there are continuous discussions on this. The open-plan office was a result of the request for reduced height of the building, probably a result of economic restrictions, a guiding from the Ministry of Defence. The employees also complain about the doors to the toilets constantly seeming to be open, when not in use. The aesthetics of the building is also disliked:

> *This looks like a hospital!* User, Visund

White and light grey interior colours are chosen to decrease the need of lighting. This may have created the hospital-associations. However, as time went by, this negative attitude to the aesthetics of the building has changed. A decoration committee has worked with art and interior, making it less hospital-like.

<u>*Ventilation*</u>
At Skarpnes the residents find the air quality good, even better than in previous dwellings. The ventilation system can be set at three different levels. Two of the families interviewed use level 1, and one family used level 2. Level 3 is experienced as too noisy. They also ventilate through windows, but much less than in previous dwellings. Some of the residents are less bothered by pollen than they used to be. Relative humidity is experienced satisfactory. The air exchange is completely dependent on the ventilation system:

> *Air quality is good, much better than in our old house. Once the ventilation stopped, and quickly the air felt moist and heavy.* Resident, Skarpnes

> *Level 1 is sufficient. Even at a low level there is no condensation on the mirror in the bathroom.* Resident, Skarpnes

However, the ventilation system does not function optimally in interplay with the heating system. There is still need for improvements:

> *When we open the window in the sleeping room, we tighten the crack underneath the door with a towel. Otherwise the convector in the hall starts heating.* Resident, Skarpnes

At Visund they have had challenges with too much dust in the open-plan offices. Some complained on health ailments like sinus, congestions and headaches. The people who felt most troubled got to move from open zones to quiet rooms. Measurements of the air was conducted by a neutral company, which stated that the air quality was good. The assumption is that a lot of dust arose when unpacking old office material. Active measures have been to change cleaning procedures. Some of the users were given larger airflows. According to the project leader, the dust problem is now solved (November 2016).

<u>*Temperature*</u>
At Skarpnes indoor air temperature is experienced as good during winter *and* summer, after the first 10 months. Adjustment possibilities of temperature function well through thermostat, window opening, solar shading, and ventilation air. Most of the residents want to have 22-24 degrees indoor during the winter, but they want a lower temperature in sleeping rooms. They all used to open bedroom windows during the night for fresh air and lower temperature. Summer indoor temperature was not perceived as too warm. This might be due to the automatic external sunshades.

> *Temperature is good both summer and winter. We had high expectations towards thermal comfort.* Resident, Skarpnes

> *We like to have high indoor temperature, 23-24 degrees. In the bathroom, 26. It is wonderful that it is fast and easy to warm up. Here you can have it both ways.* Resident, Skarpnes
>
> *You do not have to worry about having a pleasant indoor temperature in this house. It is seldom below 22 degrees.* Resident, Skarpnes

At Visund the indoor temperature was set to 21 degrees. The building was heated through the ventilation system combined with heating from radiators. The employees experienced the indoor temperature as too cold when moving into the building in December (2015). In the cold season and before any measurements were carried out, some of the employees used the opportunity to override the radiators. The indoor temperature was then set to 22,2 degrees, and the complaints stopped.

Light

At Skarpnes, the residents find the light conditions good. However, there are small windows in some zones. External sunshades are used during the summer period, and are functioning well.
At Visund, the external sun shading is not functioning optimally. This is, among other things, due to reflections from the roof on neighbour buildings. The employees have great problems with glare and disturbing light on the computer screens. Indoor pleating curtains is one of the measures to improve the situation, and the users are now more satisfied.

Lighting is to be controlled automatically by daylight. The intention is; you come into a room and get enough light, you leave the room and the light turns off. Users have reported that this does not work. In some places there is full illumination at all time (even at night), elsewhere, the light is very dim. There is no possibility to regulate this, except in meeting rooms and zones where there are light switches.

From the beginning, the lighting regulation has been poor. This is a challenge for the users and the project management. Energy consumption has been higher than expected in this area. The light is also taking more energy than calculated. Better management and individual adaptation has improved the situation.

Acoustics

At Skarpnes the residents find the acoustics good, except when the ventilation is on level three. Then it is experienced as noisy. The area where the houses are located is experienced as quiet and good.

At Visund the residents experience more sound through the walls and floors than in the old office building. Investigations, however, conclude that the acoustics are good enough according to the requirements.

Summarizing reflections

In general, the practical domestication (Godbolt, 2014; Sørensen, 2006) of the zero emission dwellings at Skarpnes seem to have gone quite well. The residents have, after some insecurity in the starting phase, taken the technology and the building into their daily practices. Measurements of energy consumption show that the residents spend more energy than the developers planned and simulated. However, PV works well and produces more than calculated. See also the next section about symbolic domestication.

However, the practical domestication in the first phase at Visund has not been optimal. The users struggled with many aspects of the building, like temperature, light and sun shading. Nevertheless, it seems like planned measures have improved/ can improve the conditions. It takes time to get used to a new building, and it takes time for a building to be adjusted to users. Why did it fail in this first phase? It might have something to do with the symbolic and cognitive domestication.

Symbolic domestication

The symbolic dimension of the new technology, the new buildings, is another important part of the evaluation. The users interpret sustainability in ways that allow them to make sense of these issues, to uphold their identity and to be helpful to the public self-presentation they wish for. In the symbolic domain, a higher (order) "value" may be attached to the use of the object, which is capable, in some instances, of conveying parts of the users' identities to their surroundings (Godbolt, 2014; Sørensen, 2006). How do the users identify with the zero emission concept and building?

Why did the residents at Skarpnes buy a zero-emission house? Location, design, high comfort expectations and a completely new house were mentioned as important arguments for buying. They selected the location because it had better value for money than in Oslo. In addition, most of the residents had family relations in Arendal. They are positive towards the zero energy concept, and think it is a future oriented concept. They also believe in PV, even if it will not pay-back when selling.

> *Somebody has to start.* Resident, Skarpnes

The residents also expect less expenses for energy spent in daily use. They cannot be regarded as pioneers or environmental enthusiasts. They are averagely interested in these matters. They are positively minded to saving money due to the PV-system. Two of the households are conscious about *when* to use energy. However, in line with what was in the literature described as household-level rebound effects (Throndsen & Berker 2012; Winther & Wilhite 2014), saving energy one place may lead to using more energy other places:

> *We use the delay function for the washing machine and dish washer in order to use electricity from PV during the day. But we also have installed a jacuzzi in the bathroom.* Resident, Skarpnes

> *We do not pay much attention to energy use. We do things as usual. We are not too good at switching things off.* Resident, Skarpnes

> *We are no idealists; we separate waste, but we do not make things more difficult because of the environment. All visitors think it is cool with PV.* Resident, Skarpnes

The residents use more energy than calculated according to one from the executing party at Skarpnes:

> *Zero Energy, yes. However, some will put a jacuzzi in the garden. That's how it is. But they are welcome to do so in their own home.* Executing party, Skarpnes

The zero-emission concept was not mainly what they identified with when moving in, but they are positive towards the environmental focus. At the same time, the dwellings function well, there are no frustrations, and therefore the positive attitude towards the building remain. The interest for environmental measures grow. However, as most people they keep an energy account balancing input and output – if they are energy efficient at one aspect, they may consume more energy on other measures (Godbolt, 2014).

At Visund, the users felt overseen in the first phase. There was frequent contact between the project leader and the user representative in the pre-project, but the users were not involved in the decision to reduce the number of floors. The contact between the project leader and the user representative was frequent in the takeover phase, however, at that stage the main choices were already taken. The project leader had been listening, and actively tried to find measures on sun shading and heating when needed. The dust problem has been tried solved with more frequent cleaning.

The importance of user involvement in the building process is significant, and at Visund the user involvement has been limited in the first phase. According to one of the informants of the building process, the short conceptual design phase did not give enough room for anchoring the concept among the users. This dissatisfaction remained during the whole project period. It was strengthened through 1) new user needs in the long break between the conceptual design phase and the detailed project (staffing and tasks), and 2) the difficulties of accepting changes decided on the ministry level, with mainly the reduction of number of floors with open-plan offices as a consequence.

Even if some of the employees did not want to sit in an open-plan office, they were told to do so by the management group of their organization, supervised by the Ministry of Defence. Transition to open-plan offices is known to be a challenge. The idea of traditional cell offices is often deeply rooted in organizational culture. Transition to open-plan offices requires a change of working methods, and a change of attitude towards sharing and communicating in the organization (Skjæveland, 2012). Since the transition to an open-plan office was experienced as challenging, this may have negatively influenced the process of moving into the new building, and contributed to negative attitudes towards the practical challenges with the building.

In addition, the limited user involvement in the building process directly affected the way things were planned and designed, and further influenced the experience of the building. The users (user representative) were e.g. not invited to the ZEB-workshops, and were accordingly not included in the development of ZEB-related solutions. The user might not have been interested in all of this, but in many ways the solutions affect the functionality of the building and thereby the users. The user representative said:

> *We have just been informed when things began to take shape. (...) We have not been involved in this part at all. (...) We, the departments, we have been concerned that we get the offices we want, we get the systems we should have and concrete solutions. Saving energy when the elevator goes up and down and all that has not been a factor to us. We see the value in it. But it has not meant anything to us.* User, Visund

When asked about the employees' awareness of working in a zero-emission building, the representative answers:

> *Yes, I think some of them are. Now I speak for others, but I think most of them do not have any relation to it (the environmental aspects of the building). People are more like "I am supposed to just have an office." (...) I think people have a more practical attitude towards the building. But of course, some think the solutions are exciting. But it does little good when the solutions chosen do not function. I am talking about lighting in particular. (...) We must accept that it takes some time to get used to the building.* User, Visund

The employees' attitude towards the building is influenced by the lack of identification with the zero emission project. It seems like the user evaluation of the office building is marked by limited user involvement during the building process, and the forced transition to open-plan offices. Probably, a stronger user involvement in the ZEB-concept would have resulted in a stronger ownership towards the green building and further more tolerance for failures in the running-in phase of the building (Leaman and Bordass, 2007). The forced transition to open-plan offices probably made the tolerance for mistakes and challenges lower than it could have been. In general, change is not easy and takes time. Getting used to new office environments takes time.

Cognitive domestication

Living and working in a zero emission building have to be cognitively appropriated to allow people to make use of available technologies and behavioural options (Godbolt, 2014; Sørensen, 2006). Cognitive aspects are related to learning, how and in what ways users are given a chance to get to know a technology, how they come to learn or teach themselves or each other, how to use it - and, of course, whether learning occurs at all (Sørensen, 2005).

At Skarpnes the residents were a bit insecure of the technology. They tried different settings and were satisfied with the options. However, not everybody were interested in an app for controlling the technology. The residents said that they needed more information about operation and use of heating-, ventilation- and PV-systems. The zero energy concept was not sufficiently attended to either. The residents got 10 minutes of guidance at the takeover of the dwelling. If they wanted to increase the temperature, many of them did not know what to do. The residents felt insecure and needed assistance. One of the interviewees from the building process at Skarpnes said:

> *I think the residents should have received better information early in the process. It appears that they are insecure about the technical solutions.* Executing party, Skarpnes

Also at Visund the transition to the green building at a cognitive level was experienced as frustrating. The building has no possibility of individual control of light, temperature and shading. According to the executive party, this gives good control of the building's energy consumption, and ensures that it is possible to reach the energy measures. It is, however, in some cases, made exceptions in terms of temperature setting in some of the cell offices.

> *The users have gone from a building from 1963 to a new building with a different design. Things are getting better, and you get used to it. But at the same time a need for changes that you feel compelled to undertake has arisen." (...) "We are just in the month of May, we have not been here long. (...) When one moves into one's own new house, it takes a while before everything is in place. We need to really accept that. But it should not be like this in three years. (...) We'll see what happens.* User, Visund

As previous explained, knowledge and understanding are identified as crucial factors for influencing comfort in green buildings. Users are much less satisfied when they cannot understand how things work or are unable to control temperature and ventilation (Leaman and Bordass, 2007; Nicol and Roaf, 2005; Brager and deDear, 1998; Thomsen et al, 2013). Better information can help avoiding "wrong" use and increase the understanding of why things eventually go wrong. User involvement and identification with the building also influence the cognitive understanding, and the acceptance of learning and time consuming adjustment phases.

The perception of personal control over the environment increases satisfaction with energy efficient (green) buildings (Thomsen, 2013; Hauge et al, 2011). This may be one of the reasons why the users in the dwellings at Skarpnes are satisfied with the buildings. The users can act on the technical systems, or at least ask for assistance. Luckily, the technical systems at Skarpnes work quite well. If the systems had failed, the cognitive domestication of the systems, the learning of how to use the systems, would have been much more critical. The limited information and learning would have influenced the evaluation of the dwelling to a greater extent if the systems worked poorly.

Lack of personal control over lighting, heating and ventilation is common in new office buildings as Visund. The lack of control does not become critical before the systems fail, and the limited cognitive domestication affects the evaluation of the building.

User evaluation compared to project group evaluation of the building

The *zero-emission concept* in the pilot buildings is visible through architecture and technical systems framed by the building owners and the project team.

At Skarpnes, the users enjoy the zero emission dwellings and identify more and more with it, even if the energy efficiency was not the main reason for buying the house in the first place. However, the Skarpnes dwellings are not used completely according to the intentions. The energy consumption is not in accordance with energy simulations (Thomsen, Gullbrekken, Grynning, Holme, pending). In that sense, the buildings are understood in other ways than intended. The use of energy in the dwellings are maybe more of an environmental balancing act between different habits and actions, like it is for most people (Godbolt, 2014). The question is whether we expect too much energy efficiency of people in general. Or if the ZEB-concept in any case contributes positively to the environment. Even if there is a gap between intended and actual energy consumption in many green buildings (Hinge at al. 2008), the new energy efficient buildings consume considerable less energy than traditional buildings (Larsen et al 2010; Klinski et al., 2012).

The energy profile of the buildings is usually not the primary motivation for people to live or work in zero emission buildings, and the users may therefore not behave in the most energy efficient way. Users in new buildings may also be mostly interested in having a completely new building, whether it is energy efficient or not (Hauge et al., 2011). At Visund, the users do not seem to care much about the environmental concept. They might not be interested; however, the lack of interest may be due to the absence of involvement in this part of the process.

A stronger involvement in the "project within the project", the ZEB-concept, would probably have led to stronger identification with the green building, and a better understanding of the environmental aspects of the building. In the method section, we mention the challenges of the interview phase colouring the results. If the interviews with the users were done a year later, the results probably and hopefully would be different and more positive. The success of the building, from the users' point of view, may hopefully begin now.

6. Conclusions

The aim of the case-studies and this report is to address the following goals:

1. Identify and analyze characteristics of processes leading towards zero emission buildings through studying experiences, drivers and barriers.
2. In the relevant case studies, identify and analyze aspects influencing the use of zero emission buildings.
3. Based on the results, give recommendations on how to plan a successful process towards a zero emission building project with high quality.

In this chapter, we will summarize and conclude on these interrelated goals.

6.1 Characteristics of processes leading to zero emission buildings

Did the actors involved in the four pilot projects succeed in designing and constructing nearly or fully zero emission buildings? The answer is yes, they did, or seemed to do, in the not yet completed projects. However, not without dedicating "something extra", pushing these projects into the field of zero emission building.

We have seen that the four pilot projects have one important common denominator; the involved actors are trying to do something not done before. We have pointed out that this enhances needs for innovation and acceptance of risk and change, compared to a "traditional" building project. We have also pointed out that there are several characteristics of project organizations, which must be considered when deploying innovation (Harty, 2005). In the discussion part, we therefore regarded the implementation of the ZEB-goals as a project in itself – or as a "development project in the building project".

When we look at the design and construction process, we see that the (more or less conscious) focus on the formal and informal implementation of the goals played an important role for the process succeeding. All four pilot projects had a "high score" within each of the six "development project within a building project" elements. These elements can themselves be seen as characteristics of successful ZEB processes.

Are ZEB-processes unique compared to "traditional" building processes? Yes, they are. At least as long as ZEB solutions have not yet become state of the art in the construction industry. We have seen that implementing ZEB ambitions requires extra attention as a "project in the project". Based on Roger's model for Innovation Diffusion (Rogers, 1962 – Fig. 3), we might say that the actors involved in the pilot projects are early adopters. They are interested in innovation, willing to take some risk, and they are respected and influential actors in the industry.

But can we say that ZEB requires fundamental changes in the building processes as such? If we look at the ZEB pilots as a part of a bigger picture, we might say yes. The need for more sustainable and energy-efficient building is one of many trends and challenges requiring a change in the way we create our built environment[18] . Pilot projects have a value of their own as important arenas for learning and knowledge building, based on a collaboration between authorities, R&D environments and industry actors. The experience from mastering the unknown and finding new solutions creates more confidence

18 See the section "Towards new and greener shores – trends and transformations" in Chapter 2.

and openness for attending future projects with even higher ambitions. The experience from pilot studies can make it easier to communicate the possibilities to other actors in a credible way. Pilot projects as part of real life building projects are an important instrument in Norwegian R&D projects and programmes. Their impact (or success) depends, however, on the suitability of the building projects as testing and learning arenas. We have seen that the balance between the complexity of the project, the competence of the actors and the level of ambition is critical in this regard.

When we look at the ecosystem of change-drivers (Moum, 2016 – Fig. 4), the ZEB Centre and the pilot projects can be regarded as incubators for change. Together with the enthusiasm of bottom-up drivers, the systematic top-down push of authorities, standards and strategies, and the enabling power of new technologies, such pilot projects can help the construction industry to "cross the innovation chasm" between early ZEB adaptors and the majority of the construction sector and society.

6.2 Successful processes with successful buildings

There is not always an obvious correlation between a successful process and a successful building. There are many examples of building projects where the process has been successful, but not the resulting building and vice-versa. The Opera-house in Oslo is a famous example of the latter. The project organization has struggled with the processes. The resulting building is, however, perceived as a huge success by (most of) its users, by the visitors and by the city. The opera has become a signature building of Oslo and a driver in the development of an entire neighborhood.

We have evaluated both the design and construction process, and the early use phase after the handover. We have looked at drivers and barriers for the project organizations and the processes, from first idea to a completed building. We have looked at users' acceptance and satisfaction after they have moved in, and the measures taken to solve their problems.

The handover of the building from the executing project organization to the building owners and users is a critical milestone. This milestone can be a disruption, or it can be a smooth transition between design and construction, and the use of the building.

The handover typically represents a substantial shift of responsibilities, approaches and mind-sets. On one side of this milestone we have the actors who have been committed to and paid for delivering a product. The process-related success (or performance) is measured by the project organization's ability to deliver the building on time and within budget, and in accordance with the client's requirements. Whether the executing parties have succeeded in doing things the right way, is influencing the profitability of their job. Their knowledge and competence is a basic pillar in their competitiveness and even the survival of their companies. On the other side of this milestone, we have the building owner, the facilities management staff, the users and the neighborhood (society). For these actors, the resulting building is in focus. Has the project organization done the right things? They are concerned about usability, flexibility, architectural and technical quality, energy efficiency, sustainability and durability.[19]

The four pilot projects indicate that a traditional handover can be a critical barrier (or a pitfall) for achieving both successful processes and successful buildings (Fig. 13).

[19] The success of a building can for instance be measured by quantitative indicators, such as the costs related to energy use, operation, cleaning and maintenance. The success can also be described by qualitative indicators, such as the users' perceived level of esthetical issues, comfort and well-being. As the building is part of a context, such as a neighborhood, a city, a community, a specific topography, there are also a number of external factors to be considered.

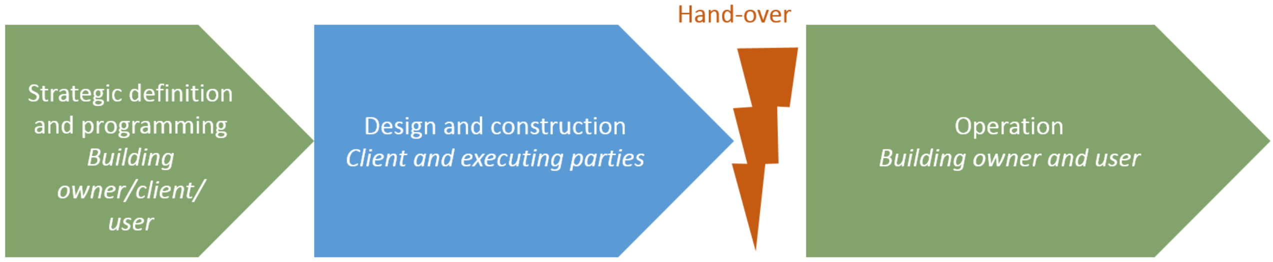

Figure 13. The handover as a "gap" between design and construction, and operation.

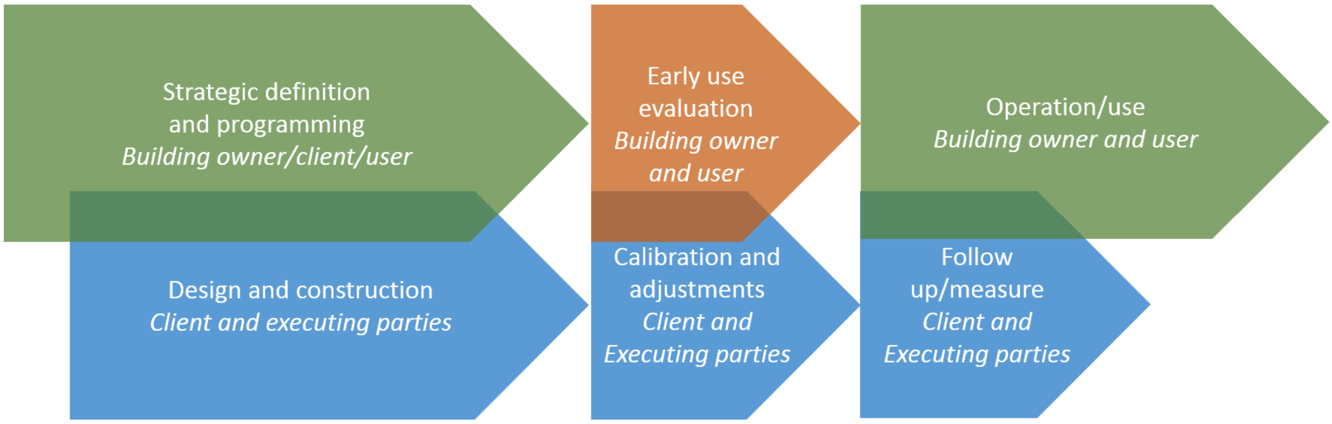

Figure 14. "Closing the gap" by a domestication phase and the continuous collaboration between client, users and executing parties throughout the entire building process.

6.3 Recommendations

Currently, where zero emission buildings are still in their early adopters phase, these projects are different from traditional (TEK10) buildings, and require extra effort and achievement from all involved parties. Based on these four pilot studies, we may give some recommendations for successful future zero emission buildings:

- To regard the process from high ambitions to good buildings as a development project of its own, requiring careful planning, management and follow-up.
- To formulate clear goals, connected to an understanding of purpose and legitimacy. The clients, the executing parties and the building owners and users have to be committed to the goals.
- To motivate all parties for "mastering the unknown".
- To focus strongly on collaboration and involvement in procurement forms and contracts, through management style and trough the establishment of good meeting arenas. It is important to involve production actors[20] early in the development process.
- To make available extra resources for the project, such as money and time. Zero emission buildings are per 2016 innovation projects, and innovation requires more resources than traditional building projects.

[20] Builders, producers, site workers and others.

- To utilize the support and competence of experts (consultants or researchers) and enthusiasts to gain sufficient competence and increase the personal engagement among the project parties.
- To follow up the commitment and the ZEB-goals after handover.

In addition, the pilot cases revealed the importance of the hand-over phase and how to make this phase easier, and thereby increase the chances of succeeding with the building. These advices are important in all building processes, but especially important not too loose sight of in zero emission projects:

- To work for continuity in project ownership. For instance through public-private partnership-models or other formal means of committing the clients and/or executing parties to the operation and facilities management of the building.
- To involve the users (and the FM-staff) at an *early stage* development. Mapping actual needs and challenges.
- To create ownership and understanding of the consequences, benefits and challenges given by the zero emission concept among the users. This will prepare for higher user acceptance of challenges in the running-in phase after handover.
- To commit central actors in design and construction to follow up with improvements and evaluations in the early use phase.

6.4 Further research

Several ZEB pilot buildings were still not completed and taken into use by the end of the lifetime of the ZEB Centre (2008-2016). We recommend conducting further studies of ZEB projects, which includes evaluations of both the building processes and the resulting zero emission buildings. Such studies are important for further research, for a more detailed picture of the challenges, and for the strengthening of findings. More research is needed on how to "cross the chasm" between ZEB as pilot projects for the early adapters and ZEB as an established practice for the majority in the Norwegian construction industry.

Further, there is a need for a broader perspective on the building in a smart city context, and a need for a focus on how the societal context influences the users' evaluation of the building. This is the research topic in ZEN, the new FME-centre led by NTNU: https://www.ntnu.no/zen.

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APPENDIX

Intervjuguide for involverte aktører i ZEB pilotbygg, byggeprosess

Person

- Utdannelse, stilling.
- Rolle i prosjektet, grad av involvering/ fornøyd med dette?

Prosjekt

- Hvordan vil du beskrive prosjektet? Hva har skjedd hittil?
- Hvordan vil du beskrive dette prosjektet i forhold til andre prosjekter du har vært involvert i?
- Hvilke forventninger hadde du til prosjektet før oppstart? Hvilke miljøer har store forventninger til prosjektet?
- Er prosjektet viktig for deg?
- (Hva skal til for at prosjektet blir realisert?)

Ambisjoner, målsetninger

- Hvilke erfaringer har du med ambisjoner og holdninger i prosjektet? Utfordringer?
    - Er du fornøyd med ambisjonene?
    - Endret ambisjonene seg underveis? Hvorfor?
    - Hva påvirket ambisjonene?

Organisering av prosjektet

- Hvilke erfaringer har du med organisering og samarbeid i prosjektet?
    - Har samarbeidet vært godt?
    - Hvor mye tid ble det brukt på de ulike oppgavene, hva tok lengre tid enn forventet?
    - Hvem gjorde hvilke oppgaver, og når ble de utført?
    - Hvilke oppgaver var mest utfordrende?
- Hvilken entrepriseform ble valgt/ hvorfor? Hva er erfaringene med denne entrepriseformen så langt?
- Hvilke erfaringer har du med type ledelse i prosjektet?
- Er det noe du tenker burde vært organisert annerledes?

Læring og kunnskap

- Har du hatt nødvendig kunnskap for å jobbe med dette prosjektet? Evt hvordan har du skaffet deg kunnskapen?
- Hvilke tema har du lært noe nytt om i løpet av prosjektet? Hvordan har du lært?
- Hva har påvirket læring og kunnskapsutveksling i prosjektet?
- Er det noe som du eller prosjektet hadde hatt behov for mer kunnskap om?
- Hvordan vil du bruke kunnskapen framover i andre prosjekter?
- Hvordan jobber de ulike fagområdene sammen?
- Hvordan fikk man på plass riktig kompetanse i prosjektet?
- Entreprenørenes og håndtverkernes kunnskap?

Kostander

- Hvilke erfaringer har du med kostnadene i prosjektet?
- Spør om tilgang til budsjett: Hva kostet de konkrete løsningene?

- Ble økonomien i prosjektet som forventet? Hvorfor / hvorfor ikke?
    - Hvordan er kostnadene sammenlignet med andre prosjekter (referanseprosjekt)?
    - Hva var de største kostnadsdriverne i prosjektet?
    - Hvordan er vurderingen og håndteringen av merkostnader?
    - På hvilken måte styrte økonomien valg av byggemåte og byggetekniske løsninger?

Samfunnskontekst

- Hvilke erfaringer har du med økonomiske støtteordnigner (Enova og Husbanken, evt kommunen) opp mot prosjektet?
- Hvilke erfaringer har du med kommunen, kommunale planer, loverk og retningslinjer opp mot prosjektet?
- Hvordan bør standarder og normer utformes for å støtte nullutslippsbygnigner?
- Hvilke betydning har sertifiseringsordninger (Breeam o.l.) eller energiattest hatt for prosjektet?
- Hvilke erfaringer har du med det å være et forbildeprosjekt i regi av (ZEB,) *Future Built eller Framtidens bygg* (råd og oppølging)?
    - Hva slags betydning har denne forbildeprogrammer for bedriften, nabolag/by, eiendomsmarkedet og byggebransjen?

Evaluering av resultatet/ planlagt resultat

- Hvilke synspunkt har du på det arkitektoniske resultatet?
- Hvilke synspunkt har du på det tekniske resultatet (energi, miljø, innemiljø, bygningsfysikk)?
- Hvorfor ble de ulike tekniske løsningene valgt?
    - Konvesjonelle løsninger eller løsninger utviklet spesielt for dette prosjektet?
    - Hvordan ble de undersøkt og dokumentert i prosessen?
    - Hvilke aspekter var avgjørende for valgene (drifssikkerhet, investeringskostnader, usikkerheter mht fremtidige brenselpriser eller leveranse av brensel)?
    - Hvem og hva påvirket disse avgjørelsene?
    - Hvordan knyttes utfordringene med ambisjonene opp mot valget av tekniske løsninger?
- Hvilke verktøy ble benyttet, og hvilke erfaringer har du aktørene med disse?
- Hva kunne vært gjort annerledes?
- Hva trengs av ny teknologi, metoder, verktøy?

- Noe annet av erfaringer du ikke har fått formidlet?

The Research Centre on Zero emission Buildings (ZEB)

The main objective of ZEB is to develop competitive products and solutions for existing and new buildings that will lead to market penetration of buildings that have zero emissions of greenhouse gases related to their production, operation and demolition. The Centre will encompass both residential and commercial buildings, as well as public buildings.

NTNU – Trondheim
Norwegian University of Science and Technology

SINTEF

ZEB The Research Centre on Zero Emission Buildings

FORSKNINGS-SENTER FOR MILJØVENNLIG ENERGI

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www.protan.no

Caverion Norge
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