Domestication, acceptance and zero emission ambitions: Insights from a mixed method, experimental research design in a Norwegian Living Lab

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Abstract:

The Trondheim Living Lab is a detached single-family zero emission building (ZEB) that is planned to reach a zero-emission balance over the course of its estimated 60-year lifetime. This is achieved by a broad variety of technical strategies such as passive and active energy design and efficient installations, as well as calculations of embodied emissions. In qualitative experiments conducted between September 2015 and April 2016 six different groups lived in the house for 25 days each. Based on direct observation (mainly through sensors registering temperature, humidity, CO_2 levels and energy use), participant observation and interviews before, during and after the stay, the paper analyses the unfolding domestication of the building along three dimensions; practical, symbolic and cognitive. The paper provides an account of which expected or unexpected occupant actions matter in which way for the zero emission ambitions of the building. Moreover, by studying the way in which the six groups within the three different categories student, family and elderly experienced living in this demonstration building this paper contributes a more detailed understanding of the overall acceptance of a ZEB in Norway.

Keywords: energy use; zero emission building; domestication

1. Introduction

The built environment is commonly described as a sector with a large, cost-efficient potential of greenhouse gas (GHG) emission reduction (IPCC 2014; McKinsey&Co 2009). According to the 2010 *Energy Performance* of *Buildings Directive,* member states of the European Union are expected to implement building regulations that require all new buildings to be 'nearly zero energy' by 2020. The Norwegian government has followed suit, and aims to improve building regulations to nearly zero energy by 2020 (White Paper No. 21 2011-2012). Following a short but ambitious series of policy measures that produced a large number of passive houses, since 2017 new energy rules in the building code prescribe energy demands that reach 'passive house level' for all new buildings in Norway. The next step, pioneered by the largest construction-related research milieus in Norway, is buildings that not only reach a zero *energy* balance but also include *GHG emissions* into the life-cycle analyses.

In Norway, the Research Centre on Zero Emission Buildings (ZEB) has laid the groundwork to specify and define 'nearly zero energy' as 'zero emission', i.e. that GHG emissions related to construction, material, operation and demolition of the building are offset by renewable energy production on-site during the course of its life-time (Mamo Fufa et al. 2016). The Trondheim Living Lab is one of these projects combining demonstration with research on the viability of the concepts and technologies developed in the ZEB centre. To date, some research has been done on the role of engineers and craftspeople in making ZEBs (e.g. Müller 2015; Søraa Forthcoming), on the role of standards and building codes for ZEBs (e.g. Müller and Berker 2014), or on expert and policy maker perspectives, and zero carbon governance (e.g. Cherry et al. 2016; Walker et al. 2015). Moreover, although some research has studied inhabitants in high-performance or smart technology homes (e.g. Day and O'Brien 2017; Skjølsvold, Jørgensen and Ryghaug 2017), not much research has been done with actual inhabitants of zero emission buildings.

This paper provides results from qualitative experiments conducted to examine the way in which people arrange their lives in the ZEB Living Lab in Trondheim. This study compares six different user groups where two groups are similar: two student groups, two family groups and two elderly groups. Each group stayed in the house for 25 days. Rather than assuming that one can study a new, stable, 'zero-emission' lifestyle, this paper identifies the impact the ZEB and its inhabitants had on each other during the 25-day period. This is useful in assessing the way and extent to which high technological, zero-emission buildings can be implemented and used in the future. In order to assess this, we study the interrelated process of negotiation and adaptation—what we call domestication or the process of normalisation—happening between the occupants and the zero-emission building. Hence, this paper deals with the negotiation between the social and the material observed when people with established everyday habits and routines inhabit a 'zero-emission' space. We therefore ask: to what extent do existing habits of the six groups concur with expectations about the 'zero emission' home-situation, and how do these existing home living habits affect the zero-emission ambitions of a house?

The paper is structured as follows. The next section discusses domestication theory and how it relates to the study of everyday life, energy use at home and ZEBs. Section 3 outlines the methodology and data used in this paper, section 4 describes some selected scripts of the building before section 5 goes through some of the aspects of living in the laboratory interpreted through the lens of domestication theory. Section 6 concludes the paper.

2. Domestication and low carbon building occupancy

–What does it mean to 'domesticate'?
–It is something that is too often forgotten, said the fox. It means 'to create bonds'
Saint-Exupéry (1946, p. 71), author's translation from French

Saint-Exupery's (1946) definition of domestication 'to create bonds' is neat and simple, but it does not provide a way of analysis nor does it say much about how bonds are created. Domestication theory as applied here provides a useful way of understanding and analysing the interdependent relationships—the bonds—between humans and technology. Domestication theory emerged in the late 1980s and early 90s when it focussed mainly on how media technologies were taken into use and 'domesticated' into everyday life (Aune 1996; Silverstone & Hirsch 1992). The perspective has later been applied to a broader set of technologies that were found to be relevant in wider contexts than of the socialisation of the technology itself. Influenced by actor-network theory and a semiotic understanding of science and technology, it was proposed to understand domestication as a co-production of the social and the technical (Sørensen 2006). From its beginnings, the basic tenet of domestication theory as applied here was that there is no such thing as an 'introduction' of an isolated technological artefact into a technology-free social sphere. Instead, an evolving process goes on between people and technologies that shape cognitive, practical and symbolic meanings connected with people's everyday life (Sørensen 2006; Berker 2011). There is, in other words, a mutual adaptation between technologies and people's everyday practices.

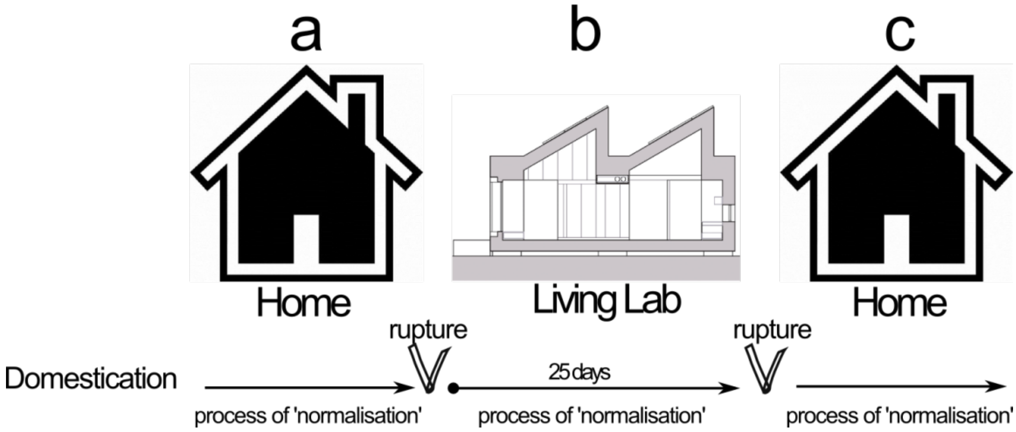
The semiotic version of domestication theory (Sørensen 2006) connects the mutual adaptation between technologies and people to the scripts that designers inscribe (Akrich 1992), and the anti-programmes that users conceive of (Latour 1992). The scripts are taken to be the representation of designers' (in our case: architects' and engineers') explicit or implicit worldviews within the artefact itself. Anti-programmes rooted in users' everyday lives can mean more or less heavy adjustments of the script that in some cases even can result in a complete boycott of the technology. Thus, technologies can be said to be 'moral enterprises' in that they include a prefigured understanding of how they should be used (Sørensen 2006, p. 56). For instance, the script of a paper cup could be 'throw me away after use', whilst the anti-programme is 'I will use this cup multiple times'. The anti-programme thus represents a kind of 'mis'behaviour on the part of the user. Acknowledging this idea means that multiple scripts are in play that are continuously negotiated in terms of anti-programmes. A house therefore can be said to contain a 'minefield' of scripts, and the domestication processes of these technologies is defined by the negotiation process between people and technologies within the house including potential anti-programmes (Berker 2011).

Beyond the recognition of scripts, Sørensen (2006, p. 47) points out that domestication theory invites a focus on three main features: 1) the practices that are constructed around the use of an artefact, 2) the symbolic construction of meanings in connection to the artefact, and 3) the cognitive processes connected with learning a practice. Since the term ‘practice’ is widely used, we here take it to mean the routines and habits that are formed in connection with technologies. In this understanding, domestication theory centres on a new material artefact, such as the mobile phone or a car, in its users’ everyday life and explores the mutual adaptation between the artefact, routines and habits, meanings and cognitive learning processes. This then enables a focus on the broader implications of technologies on the way the everyday is lived. For instance, one could study a technology; say the freezer, and how it has become domesticated through a process of adaptation applying to a wider range of routines and habits, meanings, and learning processes, e.g. connected to food preservation, cooking or eating. The introduction of the freezer (and the whole freezer chain, see Finstad 2011) introduced a change in Norwegian cooking and food storing practices. This change can also be told as a story of ‘normalisation’ in which the novelty becomes gradually embedded into the fabric of everyday life (Shove & Southerton 2000). To summarise, domestication involves a period of tension between a new technology and established habits and routines, meanings, and knowledge. During the course of domestication this tension is reduced through a process involving different strategies: the technology could be experienced as familiar part of one’s self, it could be rejected entirely, or it could tactically be relegated to the periphery of one’s everyday life. In this sense, domestication is a heuristic that facilitates the study of technological change in a way that avoids technology determinist pitfalls that see technology as acting ‘on its own’ separate from humans.

This article builds on and develops the emerging field of user-centred socio-technical studies of low carbon buildings (e.g. Walker et al. 2015). Acknowledging that users have an important impact on the performance of low carbon buildings (e.g. Gill et al. 2010, Janda 2011, Wågø & Berker 2014) we understand the interaction between low carbon buildings and occupants as an ‘interactive adaptation’, in order to ensure that complex zero-emission systems and users are well adapted (Cole et al. 2008, Chiu et al. 2014). Studies on energy efficient buildings show that technological arrangements connected to thermal comfort and ventilation are particularly relevant for the energy end-use of buildings, and this may be connected to a rebound effect as caused by increased levels of comfort (Madsen 2017; Gram-Hanssen et al. 2012, Santin 2013; Shove et al. 2008, Winther & Wilhite 2014). Some studies have also explicitly used the domestication framework to show that energy use at home is intimately bound with a complex network of doings that must be understood in order to be able to effectively ensure reduction, and that energy efficiency measures work (Aune 2007; Hargreaves et. al 2010). One recent study using domestication theory finds that living in smart and energy efficient homes can be both time-consuming and demanding, and instead of energy saving may end up generating energy intensification though new forms of energy demand (Hargreaves et al. 2017). However, since the zero emission building (ZEB) is a relatively new concept, not much research has been done to show how people actually live in them. This study therefore breaks new ground by analysing experienced comfort levels of occupants connected to the different ‘zero emission’ scripts in the Living Lab.

Turning to our qualitative experiment, all the six participant groups in this project went from one material setting, their initial home, to a new material setting, their ‘new home’ in Living Lab, and then back to their original home. As they moved from one place to the next, we can say that a new process of domestication or normalisation started, see Figure 1. To be sure, given the brevity of the stay one cannot say that the domestication process is ‘complete’ after 25 days. Nevertheless, we believe that the stay makes an impact that is interesting in itself, and the domestication perspective can be expected to shed light on the process of ‘normalisation’ of the strange, high-technological building. How—if at all—were technologies embedded into the fabric of the occupants’ everyday life? How did the occupants negotiate the various zero-emission scripts during the 25-day period? What types of adjustments were made from the perspectives of both the building and the occupants, and how did adjustments impact the zero emission ambitions of the building?

Figure 1: Domestication theory and the 25-day Living Lab period



3. Methodology

The Trondheim Living Lab[1] is located on the outskirts of the main campus of the Norwegian University of Science and Technology (NTNU), and has been the home for six groups, each group living there for a 25-day period. A living lab can be defined as user-centred experiment with the aim of testing a particular technology, solution, idea or policy in a real-world condition, where the aim is to induce social and/or technical change (Voytenko et al. 2016). The research design was inspired by the ‘quasi-experiment’ as defined by Moses & Knutsen (2007, p. 62), where a group is selected and tested before and after a ‘treatment’ has taken place. In this case the ‘treatment’ would be living in the lab for 25 days, and the ‘test’ would be the interviews before and after the stay. The research design can also be considered a variant of a ‘qualitative experiment’ since it contains elements of experimental design fused with qualitative strategies (Robinson and Mendelson 2012). We recruited participants for the project through a press release to local and national newspapers,

[1] The extent to which this ZEB functioned as a living laboratory has been reported elsewhere (Korsnes 2017), and will not be further addressed here.

announcing the opportunity to live in a zero-emission lab, and we got more than 150 applications. The two groups in each category 'student', 'family' and 'elderly' were selected based on availability in each segment, as well as the degree of similarity between the two groups in terms of age and number of children (for the families), see Table 1. The categories were decided beforehand based on relevance for present and future demographic changes: students were relevant because if the zero emission technologies tested in Living Lab become established in the Norwegian housing market, they may be expected to be living with this kind of technology in the future. Families were relevant because it is the largest group of dwellers in detached houses in Norway, and elderly because the Norwegian population is rapidly aging.

Table 1: Overview of the groups

Group	**1**	**2**	**3**	**4**	**5**	**6**
Category	Student	Student	Family with children	Elderly	Family with children	Elderly
Label	S1	S2	F1	E1	F2	E2
Details	Male and female couple, 22 years old. Live in a 52m^2 student apartment, built 1964.	Two female friends, 20 and 21 years old. Live in a shared apartment together with three other roommates, built 1905.	Mother 31 years old and father 36. Son 6 years old and daughter 2. Live in a terraced house of 185m^2, built 2007.	Husband 81 and wife 68. Live in a detached house of 170m^2, built 1980.	Mother 31 years old and father 37. Two daughters of 3 and 2 years old. Live in a detached house of 135m^2 plus 70m^2 garage, built 1987.	Husband 61 and wife 56. Live in a semi-detached house of about 120m^2, built 1959.

The data in this paper has been collected using a mixed-methods approach in which mostly qualitative data is complemented by measurements of energy and indoor climate logged every 30 seconds during the whole 25-day period. Since the various technologies and sensors of the lab were still calibrating at the beginning of the living experiment, we were not able to use the measured energy and indoor climate data to compare results stringently between groups. The logged data was therefore mainly useful to get an impression of each group individually. Moreover, since there were large differences in outdoor temperatures between the times in which the six groups stayed in the building, it did not make sense to compare the groups with respect to the energy they used. This does not impact the analysis undertaken here, which focuses on the zero emission ambitions of the house (which account for seasonal change) and the experiences of occupants.

The qualitative data has been collected based on a mixture of interviews, participant observation, diary records, a 'notebook for guests', and a camera which participants could use for self-filming. Two groups of stakeholders were interviewed using semi-structured interviews; five interviews with a total of seven people were made with the electricians, carpenters, engineers and architect who built and planned the lab, and 18 interviews with the occupants were carried out before, during and after their stay, here denoted 'before', 'during' and 'after' in the analysis (see appendix for interview guide). This makes a total of 23 interviews. The interview during the stay was conducted after around 16-18 days of residence for each group, and the after-interview was conducted around 25 days after the stay. In the interview after the stay, data of energy use and indoor climate were shown to the occupants, and perceived versus actual use discussed. This was done by first asking the occupants which devices they thought used the most energy, before showing the actual results. One of the authors did the participant observation, which varied from 1 to 5 visits per week, depending on the residents' routines. It was difficult to achieve a lot of visits with the families but much easier with the elderly and students.

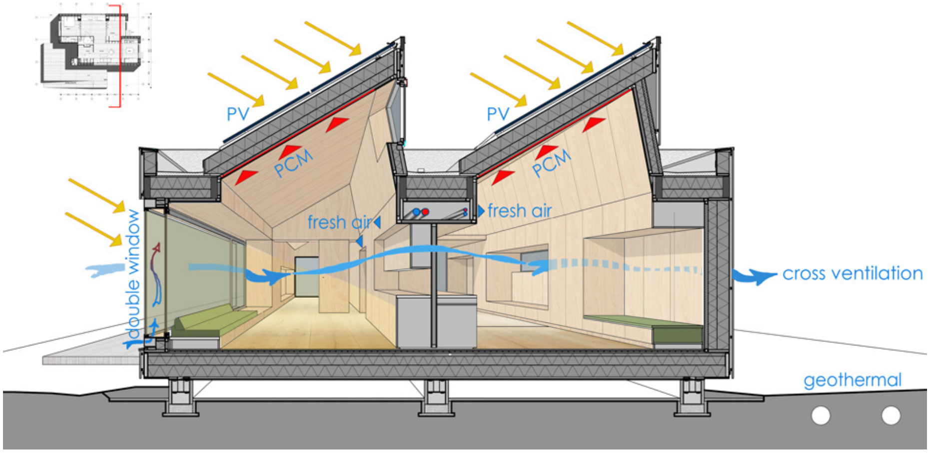
Occupants kept daily diaries in an effort to get an overview of the routines in the house regarding when the house was in use, and what type of activities were undertaken, such as cooking, cleaning, visits, dinners and so on. These diaries also had a section where the participants could write down their thoughts, reflections and experiences with the Living Lab during their stay. In addition to the six groups, one of the authors lived in the house with his family for a one-week trial period before the experiment started, in order to test the technical equipment. After all the residential experiments were over we had a focus group meeting with participants from all the groups where experiences were exchanged, compared and discussed.

4. Living Lab's zero-emission scripts

Several scripts can be said to have been working alongside and even contrary to each other within this building. These can be divided into the more technical scripts relating to the overall design and ambitions of the building as a total and the various technologies, but also to what we social scientist explained to the occupants beforehand. To start with the latter; each group was asked to make the Living Lab their home, trying to use it as they would normally use their original houses. They were allowed to bring their own furniture, and whatever they needed from home that they considered necessary. They were also given an 'instruction manual' with information about what a zero-emission building is, and with explanations of how some selected technologies worked and what they were for. This included temperature control, ventilation, the lights, the sensors, windows and the combined washing machine and dryer.

The lab embeds too many technical scripts to be covered here, but we will describe some of the key features. The house is built with an aim to reach a zero-emission balance over a 60-year period. This is achieved by minimizing energy demand for the operation of the house, minimizing embodied emissions of materials and systems, and harvesting solar energy so that production makes up for emissions caused by the building materials and operation (Goia et al 2015). One of the stated primary aims of the Living Lab is to 'realize a building that is representative, as a typology, of the most common Norwegian dwelling – the single-family house – and to demonstrate how CO_2-neutral construction can be realized in the Norwegian climate' (ibid., p. 1). The technologies used include, but are not limited to; walls, floors and roofs with mineral wool insulation of 40, 40 and 45 cm respectively, a ground source heat pump, a balanced mechanical ventilation, LED lighting, a large south-facing double skin window, solar thermal panels, rooftop adapted photovoltaic panels and a complete set of the most energy-efficient household appliances, such as dishwasher, oven and washing machine (see Figure 2 below for some of these solutions). For a complete description of all the included technologies, see Goia et al. (2015) and Finocchiaro et al. (2014).

Figure 2: Cross section of the Trondheim Living Lab



Source: Finocchiaro et al. (2014).

Worth listing here in particular is the general ambition of this building to provide a stable temperature for its occupants. Apart from the aforementioned ground source heat pump, insulation and solar thermal panels, several of the technologies in the building worked towards the aim of achieving stable temperatures. For instance:

- The phase changing materials (PCM) installed in the roof 'minimize the risk of overheating due to the lightweight construction' (Goia et al. 2015, p. 2).
- The double skin window, which 'may be used as an air intake for preheating of the ventilation air' (Andresen 2017, p. 202), including the shading system
- The balanced mechanical ventilation system, which had an electric coil capable of heating air up to 40° C.

It is also worth discussing what the architect had in mind when designing the building internally. The architect pointed out that over the course of the three-year design process, the building changed form, nature and content several of times. This was due to several things (e.g. price), but most importantly changes came about through negotiations with engineers and project managers about calculations of the embodied material emissions in the various designs. For instance, the architect had plans to have more windows and open solutions requiring glass, which was rejected due calculations of embodied emissions. In other words, the material choices make an important part of the zero emission calculations of the building, and is therefore included in our analysis.

Regarding intended use, the architect imagined that the building would fit well for two students or a young couple with a child or two. He also recognised that several of the chosen solutions would generate mixed feedback:

> some people might love the fact that the furniture is integrated into the walls, it gives a sense of larger space and so on, but some people might also hate it: they might think it is not adjustable to their own taste, they would like to move things around once in a while and it doesn't reflect their own way of living.

The architect had reflected about how his design choices might be perceived. For the architect, this building was also an experimental project that could be used to see how people would react to the different choices made. This means that the experimental status of the building also should figure as an underlying ‘script’ that would impact occupants. With this brief description of some of the scripts embedded in the building, we now turn to describe how the six groups experienced the process of domesticating the Living Lab.

5. Domestication of the Zero Emission Building (ZEB)

During the first few days of their stay all groups reported that it felt ‘strange’, ‘new’ or ‘unfamiliar’ to be in the Living Lab. They needed some time to ‘find their spots’, ‘my chair, your chair’: basically, to find out how they could arrange their everyday life. After some time, all had, to a varying degree, adapted to living in the lab. Here we describe the domestication processes of the six occupant groups divided into five different areas that were relevant for the zero emission ambitions of the building.

Overall internal building design

Precisely as the architect expected, the groups reacted to the internal design of the building. For instance, several groups reacted to the lacking door between the entry and the living room so the house got cold when someone entered, and that there were no windows in the bedrooms (only doors). The groups and their visitors commented on the built-in furniture. One example is the couch, which none of the groups liked. F1 (during) said that: ‘after we came here, I realised what a fantastic couch we have at home’. E1 (during) felt that it was designed for ‘2 metres tall basketball players’, and could be used to ‘sleep in, but not to sit in’. The built-in furniture was not only perceived as negative: it included large drawers that were particularly fun for the young: ‘The children love to play and to hide in these nice big drawers’ (F2, during). The two family groups and the elderly groups who had grandchildren visiting pointed out that the happiness of children in the lab was important for their wellbeing, and thus also the process of domesticating the building.

The open design, which the architect designed to be beneficial for the ventilation air flow of the building, generated mixed reactions. It made some feel that they could be less private, but the open design also made it feel like there was much space. F1 (during) struggled to find suitable ways of being together: ‘we cannot be properly apart, and we cannot be properly together’. They could not be apart because of the lab was so open, and they also felt they could not be properly together because they lacked their couch from home where they could sink in and get cosy. S2 (during) reported similar reactions; they had a visitor who got a call that he wanted to conduct in privacy. First, he went to one of the bedrooms, but that was occupied, then he tried to stand in the hall, hiding behind one of the walls, but it was not ideal. The interviewee jokingly added: ‘He had to make the call in the WC!’

Figure 3: Comfy chairs, plants and a television for E2

The open design was in other words strongly connected with the various set-ups for relaxing and feeling comfortable in the Living Lab, which were different to the way occupants would relax in their original homes. Setting up a comfortable space for relaxation was for all the groups very much connected with having established an area of the house where they could ‘feel at home’, feel ‘cosy’ and perform their leisure activities, such as reading, listening to audio books, using tablets, knitting, weaving, and watching television. Some of the groups succeeded with this (e.g. E2, see Figure 3—who brought their own television, comfy chairs, carpets and several plants), whilst other groups, such as F1 who missed their couch, never quite got that cosy feeling. Indeed, this idea of a cosy (‘koselig’) indoor atmosphere appears to be particular to Norwegian (and Scandinavian) culture, impacting how well people feel at home, and hence, the domestication process (e.g. Wilhite et al. 1996). It often includes candle lights, blankets, comfy chairs, carpets and wooden materials.

The open design also impacted how the groups felt about their home after they came back. Several of the groups mentioned that their old home felt small when they came home – it felt ‘boxed in and dark’, or as E1 (after): ‘Our house is much bigger, but it feels smaller than the Living Lab!’. Another curious feature that the Living Lab stay induced was that all groups felt that they had too many things when they came back to their homes after the lab-stay. Indeed, several groups decided to get rid of things or to take down wall-decoration because it felt disturbing after having been in the Living Lab. For instance, for the wife of E2 (after) it was interesting to gain an understanding of ‘how it is for refugees now, who come to new places with little things’. For them, the most valuable lesson of participating in the Living Lab experiment was that it is possible to live in a simpler house, that they had enough space, and that ‘I could manage with a third of all the things I have here’.

Double skin window

The Living Lab’s large south facing window triggered different reactions. Being a demonstration building as well as a research facility, the building is located close to a busy street close to the university’s main campus. The groups were varyingly accustomed to the fact that they were made very visible through the window. Some felt that they were too visible and kept the blinds down (which would impact the heating functions of the window), others were not as bothered about it. As S1 (during) explained: ‘The big window gives a lot of light, but we are too visible here, we feel a bit on exhibition. So we keep the blinds down a lot’. For S2 (during) it was also somewhat embarrassing to continue with their normal home habits of drying the hair with an old t-shirt wrapped around the hair: ‘I’m not going to walk around with that turban (for drying hair) on my head here’. When one of the students of S2 (during) had her boyfriend visiting over the weekend, and they wanted to lie down on the couch and relax a little, they ‘felt like it was not only us here, but the people on the outside as well’. F1 and F2 were more accustomed to the visibility, and they did not mind it as much. F1 (during) put it this way:

> We are used to the visibility from where we live already, so we are used to waving to your neighbours. And the children think it is fun to sit down in the couch here and wave to the people outside.

For F2 the visibility was not an issue, but they would still take down the blinds in the evening, because ‘it gets a bit cosier’. When the sun was shining the south facing window heated the house considerably, and it was rather uncomfortable for the occupants to sit in front of the window: ‘We had not taken down the blinds today, so it was 25 degrees when we returned from work.’ (F2, during). In other words, the double skin window had several functions apart from what the script intended.

Ventilation and airing

In highly insulated and air-tight buildings, the ventilation system gains increased significance compared with non-ZEB buildings. The building was designed to work equally well with both exclusively mechanical and with mixed ventilation. The occupants were told that they strictly speaking would not have to open windows to achieve good indoor comfort, but that they were free to open windows as needed. At the same time, three windows (i.e. all but the big window at the south facade and the three skylights) were designed as sliding doors, which led to concerns about anyone (and anything) being able to enter the building if they were open, especially at night. One group of elderly occupants who was used to sleep with open windows (which is very common in Norway) reported their surprise about how well sleeping with closed windows worked. In their case the normalisation was instantaneous, and their domestication effort, which consisted of using lighter bedding, was minimal. Another group, living in the lab during the winter period, however, after a period of experimenting, settled on sleeping with open doors, which resulted in higher energy consumption. These two groups show how normalisation despite the script inscribed in the windows-as-doors resulted in very different outcomes, not the least in terms of energy consumption.

Figure 4: Dust bunnies collected after one week, documented by S2

Several groups mentioned in the beginning of the stay that the air was very dry in the lab: ‘The air is very, very dry. The skin of (two-year-old daughter) is cracking up. (…) I brought my own humidity meter, and it shows 10%’ ‘Drying clothes is much faster here because of the dry air’ (F1, during). The husband in F1 also complained that he could not bring his cello into the house because it was too dry there. However, towards the end, and in the interviews afterwards, the dry air was not a big topic. It appeared that occupants were adapting to the dry air, either by not any longer attributing skin problems to the ventilation system or by physical adaptation. The latter possibility adds a twist to the normalisation story introducing the body’s ability to adapt to different environments.

Lastly, as reported by several of the groups, Living Lab appeared to produce more dust, and some groups connected this to the ventilation system. For instance, the father in F1 (during) said that: ‘I was vacuum cleaning yesterday and today I can see that dust bunnies are already taking shape under this chair.’ This was not necessarily a bad sight, however, as the mother immediately replied: ‘Yes, but I have read somewhere that if dust bunnies appear it means that the ventilation is good, so it is actually a good sign'. (See Figure 4 for a sample of a dust bunny). Nevertheless, the rapid formation of dust was accompanied by more frequent dusting and cleaning: 'I have been mopping the floor more often here than at home. The dust gathers quickly, after only two to three days' (F2, during). Nevertheless, this rapid dust formation was abated by the fact that the house was very easy to clean and keep tidy. E1 noted in their log: 'Cleaning the house, swiftly done ☺', and S1 even felt that the house was 'inviting to be cleaned' because of its more open space, as well as the good feeling of seeing that it was clean.

Artificial lighting

The LED lights in the building were chosen for their low energy use, and together with the light-switches they caused a certain friction. All the groups had difficulties finding the right switch because there were several freely programmable switches in each room (there were a total of 25 switches). Almost all groups found that the placement of the switches made no sense to them, and trial and error was the main way to find out which switch functioned for which light. This experience was also reinforced by the fact that the switches 'flip back so you don't know which switch is on'. This lack of visual feedback about the switches' state is part of a technical smart home script where the switches are designed in a way to enable remote control either through a smart phone or some kind of automatic control system. Some of the groups therefore kept the light on much longer than usually, because it was too difficult to find the right switch. The house also had built-in movement sensors for automated light switching, but this function was turned off during the experiment. Some of the groups nevertheless mentioned in the beginning that they were disturbed by the 'clicking-sound' from the movement sensors during the night. For the families, the large number of switches caused another source of annoyance than for the other groups: the children loved to play with the switches turning all the lights on and off, repeatedly. One of the family groups put it this way: 'there is an insane amount of switches, and the children love to play disco with them'. This might also have affected the total amount of energy use for lights, and all occupants expected the LED lights to use much less energy than they did.

The LED light itself also received mixed feedback. Most of the groups liked the lights very much as it provided good 'reading light', because 'there were even amounts of light everywhere', or because they could 'adjust the brightness' according to the atmosphere they wanted to get. One group disliked the lights because there were too many light sources, and the light was too bright even on the lowest setting. This group felt that they could not get the cosy atmosphere with the LED lights, and instead used more candlelight. Some of the occupants also found the light in the house good to work with, when correcting papers at home in the evening or doing school work. S2 had some guests that illustrated what they disliked about the lighting (Picture 4). For these guests, the LED lights were blinding people sitting in the lab. In general, however, the artificial lighting did not pose any large obstacles to the groups, and it appeared that they got quickly used to the LED light-source.

Heating and staying warm

Staying warm at home was a ‘hot’ topic for all the occupants of the Living Lab, and testing various types of heating systems has been to the zero emission ambitions of the building (e.g. Goia et al. 2015). The six groups had different set-ups for staying warm in their original homes: Two of the groups had electric heating, one group had district heating and three groups had air to air heat pumps in addition to firewood ovens. There are a variety of technologies and techniques for staying warm at home, including clothing, sunlight, physical activity, blankets or lighter bedding, as was the case one of the groups. The Living Lab was mainly heated through under floor heating generated by the aforementioned heat sources, and it would typically take up to eight hours between a new temperature was set until it was achieved.

S1 (during) reported that it was warmer for them in the lab than at their home. One reason for this was that it didn’t cost them anything to keep it warmer in the lab, but a contributing factor was the extra effort it took to change the heat in the lab: They had to use a monitor located in the entry hall to regulate the temperature in each room. As they put it:

> There are no ovens here that you can adjust the temperature on when it gets warm. We cannot regulate anything on the radiator here, and we have to go out in the hall and that’s an effort. We just put it on an average temperature that we are happy with.

For S2 (after), the comfortable temperature in the lab became visible only after they had returned back to their original home: ‘there is a draught from the windows and the floor is cold [here]. We have to close all the doors between rooms because there is a temperature difference. But there [in Living Lab] the temperature was the same everywhere so we didn’t have to be concerned about that. I even didn’t have to wear socks!’ Without thinking about it until after the stay, they automatically accepted the temperature control system in the lab. The stable temperatures of Living Lab were backgrounded and only became visible after the 25-day Living Lab period had finished. Therefore, the knowledge these students had of active temperature regulation was replaced with a passive regulation in the Living Lab. This supports a recent study of Madsen (2017), showing that underfloor heating gives a particular sensation of comfort, which is not achieved with radiator heating.

The elderly couples also commented on the stable temperatures and the difference between active and passive regulation. For them, the difference was that they could not use firewood for quick heat increases, as they would normally do at home. E2 (before) explained that they would keep the regular indoor temperature around 20 degrees or lower and typically heat with firewood as they got home in the afternoon. As the husband put it: ‘I like to light the fire when I come home and feel half-frozen. I think the heat from the firewood oven is warm and nice.’ The wife of E1 (during) explained that ‘heating takes a long time here. At home, we can use the heat pump, electricity and the firewood oven. You can heat yourself out of the house if you like, and my husband would not hesitate to do that’. Similarly, E1 wrote in their diary: ‘We can adjust the temperature up and down. But I wonder; what is the real temperature here? How quickly can we notice the change?’ In other words, the time it took to get warm was important to their comfort, and the quick temperature increase from a wood heating was lacking. E2 found a work-around, or anti-programme, for this problem: They set the temperatures a bit warmer than necessary, and then cooled the house quickly by opening the roof windows when needed.

For the two men in the elderly groups, heating with wood oven was not only something they did to stay warm but rather something they also loved doing either as a hobby including chopping and storing firewood. The husband of E2 (before) jokingly said that he 'has so much firewood he needed to "get rid of"' (i.e. that he needed to burn). In his pastime, he would spend hours in the forest collecting firewood with all the equipment of a professional lumberjack: chain saws, protective gear, tractor and hanger. Therefore, an important part of his pastime was lacking in the Living lab. Since there was no wood oven in the Living Lab, the two elderly groups felt that the cosy time around the fireplace was lacking, that their skills of wood collecting and heating were useless, and their habit of rapid heating made the stable temperatures of the Living Lab feel strange. This is not surprising, as usage of wood is a heating technology that is highly determined by the temporal organisation of everyday life (Jalas and Rinkinen 2016). However, larger use of wood is not supported in low-carbon solutions precisely because of the time and (in)convenience they require (ibid.).

Although this ZEB was designed to keep a uniform and stable temperature, the occupants indicated several times that stable temperatures were unfamiliar to them. A member of S1 noted in the log: 'I wonder if it is energy efficient with this type of open doors to the bedroom when we want to keep it 16 degrees Celsius, but the rest of the house 21-22 degrees Celsius'. The occupants' habits and knowledge of rapid heat increases and spatial temperature differences made them feel somewhat uncomfortable. Thus, although the building aimed at keeping temperatures uniform this temperature stability appeared to interfere with habits and knowledge connected to time (quick temperature increases from wood heating, as well as cold in the night, warm in the day), spatial distribution (cold bedroom, warm living room), and sensory experiences (cosy/warm fireplace).

The episode of normalisation that had the strongest impact on the lab's energy consumption in the whole experiment happened when F1 moved in. Their trouble started with strong reactions to the heating system in Living Lab:

> 'There was cold air coming in, so they hadn't turned on the air-heater. The floor heating was also not turned up. When we found out it wasn't working, and the loft could not be used, we felt a bit like …<sighing>. And on top of that, the kitchen doors were not opening the right way <laughter>'. (F1, during).

This was due to an under-dimensioned heating system that could not heat the house properly with the extreme outdoor temperatures at the time: down to minus 20 degrees Celsius at the coldest.

Consequently, F1 saw a need to bring their own heating device into the Living Lab, which impacted the total energy use considerably. The uncomfortable temperature experience in the lab had implications for other fields and impacted their total impression of the experiment. As we have seen from the above accounts they reacted to the 'lacking couch' and the dust bunnies. In many ways, their expectations about the zero emission building were shattered: they had been looking forward to participating in a 'futuristic' experiment in order to 'do something for science', but as they moved in they felt that they had been ‘moved in prematurely’ and that they were there mainly to ‘point out errors with the house’. Coming to Living Lab made them appreciate more what they had at home: a comfortable couch, friends nearby, an oven that was simple and worked, and so on. Despite their efforts – that impacted the energy consumption considerably – living in the lab never became normal for this group, and they were relieved after returning from the ‘experiment’ to ‘normality’.

6. Conclusions

–What does one have to do? asked the little prince.
–One has to be very patient, answered the fox. First you would have to sit down a little bit away from me (…), but every day you will be able to sit a little nearer’
Saint-Exupéry (1946, p. 78), author’s translation from French.

Saint-Exupéry’s explanation of how to domesticate involved patience and a specific pattern (a ‘rite’) to be followed. Although this paper does not provide such a prescriptive recipe, we have discussed the way and the extent to which the Living Lab and its inhabitants were ‘creating bonds’ with each other and presented some broader implications the zero-emission technologies have had for how its occupants lived their everyday. Similar to Saint-Exupéry’s explanation, this process of creating bonds impacted the habits and routines, meanings and learning processes of the inhabitants.

Taking a step back to see how the occupants and the lab negotiated with each other, some things facilitated the domestication process, and other things complicated it. Each group got more and more used to living there (although less for F1 that experienced a faulty heating system), and things that were different from home were either accepted immediately or after some time (for instance the wooden surfaces or the LED lights), rejected and not used (for instance the combined washing machine and dryer) or adapted to (for instance sleeping with closed windows for some of the groups, or bringing a summer duvet although it was winter). Moreover, some things were not noticed until after the stay had ended, implying that the Living Lab stay affected subconscious processes that were not immediately apparent to the occupants at the time of their stay.

The paper discussed five different arrangements that impacted the domestication process of the zero emission building (ZEB): The overall internal building design, the large double skin window, the ventilation and airing, the artificial lighting and the heating system. This represents only a selection of the scripts that affected the occupants – all of which impacted the domestication process of the building. The groups reacted differently to Living Lab technologies, as they impacted diverging sets of routines and habits, meanings and cognitive learning processes. For instance, for some, the south-facing window affected their alone-time with the boyfriend, and for some it interfered with the indoor temperature or with hair drying habits. The point here is not to count which technologies did what, but to show that the intentions of designers, planners and developers should not be provided as ‘one-size fits all’. By zooming in on some specific technological arrangements and how they were accepted, rejected or adapted this paper contributes a more detailed understanding of the overall acceptance of the ZEB.

One key finding is that although the ZEB had an ambition to perform in a certain way, practices, meanings and cognitive aspects were not in line with these ambitions, representing a break between the intentions of the house and the occupants. This was most strongly exemplified in the case of how the lab was heated: The house was optimised to provide a stable temperature, but this stable temperature interfered with temporal, spatial and sensory practices of occupants' everyday life. Thus, this study proposes that students, families and elderly groups have different set-ups for living at home, and an optimal design should be flexible enough to cater for such differences. In other words, the existing variety in occupant life phase, age and family situation means that different zero emission arrangements must be designed. This paper shows that especially for the elderly groups, the lack of a firewood oven was a major determining factor for their acceptance of the building. Hence, the justifications behind providing a strong script, such as the stable indoor temperature, should be assessed against the perceived need of occupants to get fresh air and to be able to change indoor temperature quickly and with a desired technology. Such assessments may be useful in order to avoid energy consuming and emission intense processes that may occur if ZEB functionalities do not match established practices.

This study also found that some things changed for occupants as they moved back home: For instance, E1 decided after their stay to acquire most of the household appliances they learned to appreciate in the lab, and all of the groups felt like they had too many belongings at home when they returned. Moreover, some felt that their original home was smaller and more boxed in, some felt stronger the impact of a cold home, and some groups recognised how much they appreciated their existing set-up for relaxing at home. The occupants experienced more clearly what was special in their original home – the way they were heating, how many things they had, what they liked and disliked about their present living situation compared to the one in Living Lab. Indeed, the encounter with Living Lab appeared to sensitise occupants to their current material home-situation. In other words, although occupants were staying only 25 days in the lab, the experience triggered them to re-think what they already had.

We may therefore conclude that it was not only the case that the different ZEB technologies could be misunderstood, confusing or ignored. It was also that these technologies affected occupants' understandings of their own organisation of the day, which in turn affected the way in which the different technologies were seen as useful in their everyday life. Hence, these ZEB technologies were not only becoming part of the fabric of everyday life, but they were also impacting the way in which everyday life activities were constituted. This was for instance shown in the way the stable temperatures of the Living Lab impacted the habit of heating with firewood, or sleeping with open windows, for the elderly groups, and also how the house was lighted or how the double skin window impacted occupants in different ways. In this way, the findings of this paper support other studies reporting a 'ratcheting up' of levels of comfort (Shove 2003) and an energy intensification associated with smart and zero emission technologies (Hargreaves et al. 2017). Some home living habits of the six groups only marginally concurred with the 'zero-emission' home-situation, meaning that the zero-emission ambitions of the house were affected.

These observed mismatches between zero emission scripts and occupants' expectations towards a good home present a severe challenge for a widespread acquisition of ZEBs. Therefore, the implementation of ZEB in Norway may face difficulties should such concerns be ignored in regulations and dominant designs. Perhaps more pressing, in order to realise a GHG-neutral home in the Norwegian climate, assessments of what technologies and solutions are necessary should be made according to a wider range of parameters including the availability of local energy sources and materials, or the presence of existing heating cultures. Without real-life examples with present ZEBs there is a danger that the technical GHG reduction potential found in buildings will not be achieved. This paper has started the process of outlining how ZEBs can be achieved and what kinds of technology may be included. Without this kind of user-centred socio-technical studies of low carbon buildings, we are in danger of proposing buildings that people do not want, do not need, or do not know how to operate.

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Appendix: Interview guide for occupants during the stay

Background

Can you tell us a little bit about yourselves and your family?

What does your current home look like?

Expectations

Why did you want to live in Living Lab? Is there something you want to learn/experience through living here?

Was there something in particular you were or were not looking forwards to?

Everyday routines and tasks at home

Can you describe an ordinary day in Living Lab? And on the weekend? Are there any differences between Living Lab and your regular home?

Can you tell us about how you perform these activities in Living Lab, and at home?

- Cooking and eating
- Washing and drying clothes
- Cleaning the house
- Personal hygiene / showering
- Heating
- Cooling and airing
- Lighting
- Sound conditions when doing different activities
- Spare time
- Sleeping

How is the labor division (in Living Lab vs at home) and why?

Are there some tasks that are easier/more difficult to carry out in Living Lab than at home?

How is the indoor climate in Living Lab? Did you adjust the heat? Does it smell nice? Is the air good?

How are the acoustics in Living Lab? Are there annoying sounds from outside?

How is the daylight in the lab? Do the blinds/shading system work well?

Do you pay attention to electricity use at home / Living Lab? Daily, weekly or..?

Living Lab as a dwelling

Were there any objects / things that you had to bring when you moved into Living Lab? Were there any things that were important not to bring (routines or objects)?

Is there something special about this building compared with other Norwegian detached dwellings?

What do you think of the architecture and design solutions in Living Lab?

How do you perceive the height and spatial qualities? The view? Use of materials?

Do you feel at home in Living Lab? How do you create the feeling of being at home? Do the technical solutions in Living Lab support or hinder this feeling?

Is Living Lab a comfortable home? What is necessary to be comfortable for you? Do everyone in the household agree about this? Can technologies create comfort?

Experiences and challenges

How would you describe your experience of living in the lab?

Did everything work according to expectations (technically, functionally and comfort)?

Is there anything that should have been done in a different way in Living Lab?

Do you feel like you "master" the building? Would you have liked to have more or less control over temperatures, airing, and technical control of the house? Do you feel like you can control these things so that you get a satisfactory indoor climate?

Do you feel more sustainable by living in the lab? Do you consider yourselves to be environmentally concerned people?

Afterwards

How do you think it will be to move back home?

Do you all agree about the experiences made here in Living Lab?