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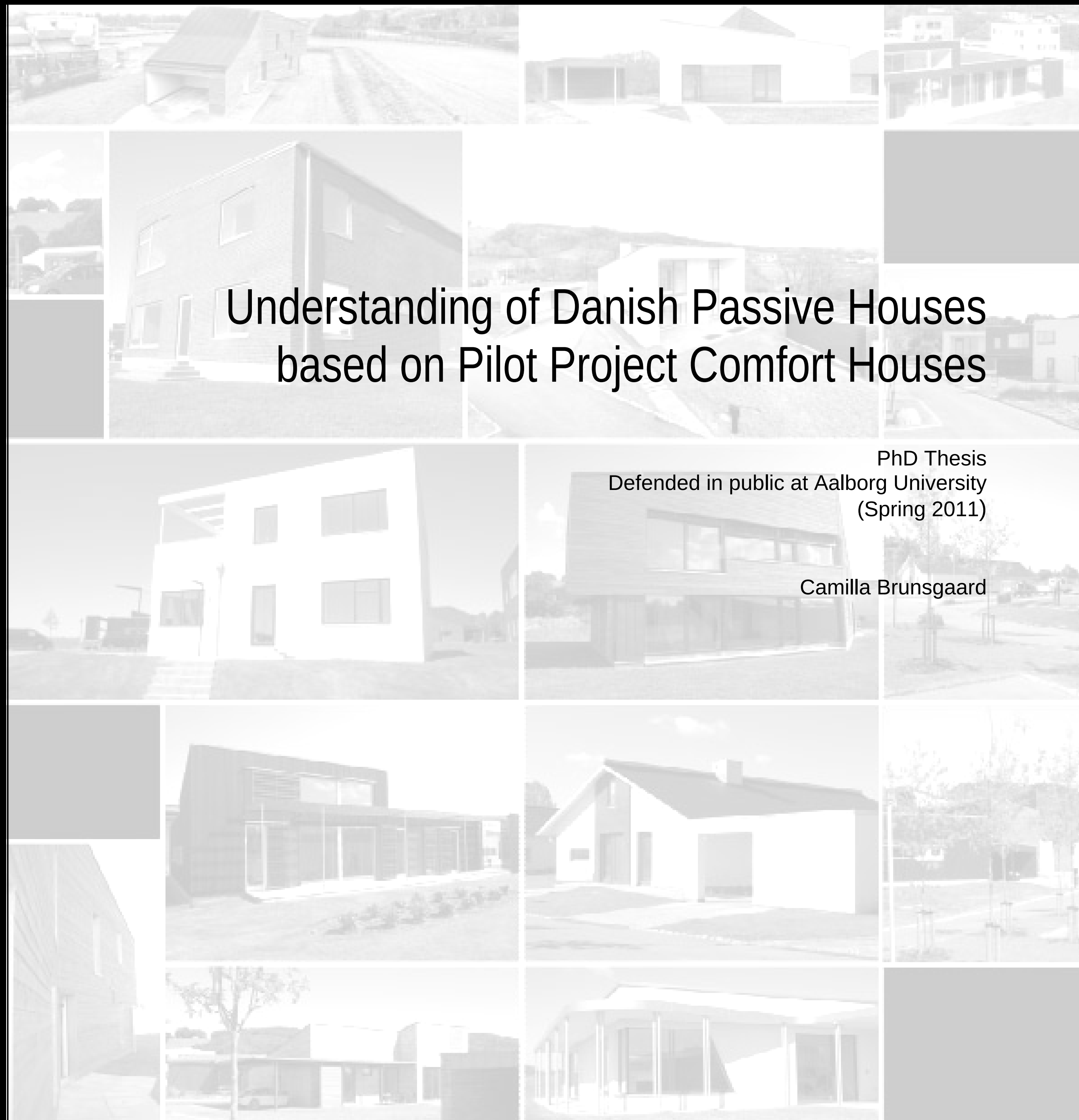

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PhD Thesis
Defended in public at Aalborg University
(Spring 2011)

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AALBORG UNIVERSITY
Department of Civil Engineering

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ISOVER

KOMFORT HUSENE

AALBORG UNIVERSITY

Department of Civil Engineering

Preface

This report is a result of a PhD work carried out from autumn 2007 until winter 2010 at Aalborg University. The research is done in collaboration between the Department of Civil Engineering and the Department of Architecture, Design & Media Technology at Aalborg University and manufacturing company Saint-Gobain Isover Scandinavia.

The aim of the PhD project was to investigate the pilot project of the Comfort Houses and thereby gather a range of knowledge about passive houses in Denmark that can support the future production and use of passive houses. Saint-Gobain Isover Scandinavia has taken the initiative to the pilot project of the Comfort Houses and had the objectives of openness and sharing knowledge within the project and with all interested in the building industry. The knowledge from this research project has been a part of the knowledge sharing together with other initiatives and has increased the awareness and given courage to the building industry to construct passive house today. When the project started there were very few certified passive houses in Denmark, today there are about 150 unites according to Passivhus.dk (www.passivhus.dk).

The investigations of the Comfort Houses was divided into different study fields to gather knowledge that would form a holistic picture of passive houses and give a holistic understanding of how to approach passive houses in Denmark. Some study fields have had more focus than others therefore the report is divided into two main parts besides the introductory, concluding and perspective chapters in respectively the beginning and the end of the report. Part I contains presentations of the Comfort Houses and study fields with a minor focus, where Part II presents the main findings of the research. In the end of the report a reference list and appendix will be present.

This thesis is based on a collection of articles submitted to international scientific journals. This means the content in the chapters in the report is summarised descriptions of theories, results, discussions and conclusions of the original work. The scientific works are found in *Appendix A – Publications* in full length and will be referred to in the text by the full source reference. (E.g. *The Critical Design Process – Experiences from the first "Comfort Houses" in Denmark*. Brunsgaard, C. et al. (2010b). I: Architectural and Planning Research).

The Ph.D. thesis has only been published in a limited number of issues due to copyright restrictions and cannot be reprinted without authorization from the author, co-authors and from the publishers of the scientific papers. However, most conference papers can be acquired through public libraries, whereas the technical reports can be acquired through the Department of Civil Engineering, Aalborg University.

Aalborg, December 2010

Camilla Brunsgaard

Acknowledgement

During this PhD work several important people have crossed my way and have in some way or another contributed to the outcome of this work. Those people has both inspired me, taught me about the building industry in practice and what it means to do research.

The Comfort Houses

Within the project of the Comfort Houses I would like to thank Saint-Gobain Isover Scandinavia, who first of all has taken the initiative to the pilot project of the Comfort Houses, which resulted in constructing some of the first passive houses in Denmark. Secondly, they have supported the PhD project financially and made it possible for me to do this research, which has given me incredible knowledge about this field – a field that has had my interest for several years even before the project started. Finally, I would also like to thank Saint-Gobain Isover Scandinavia for given me a unique insight into the building industry in practice.

During the research I have had interviews with both architects, engineers, contractors and manufactures, who has designed and completed these houses. I would like to thank those people for spending time and sharing their knowledge with me.

The occupants in the Comfort Houses should also have a great thank. I am very happy that I was allowed inside their homes and could interview them about their experiences and understanding of living in the Comfort Houses.

Aalborg University

At Aalborg University I would like to thank first and foremost my supervisors; Professor Per Heiselberg at the Department of Civil Engineering and Associate Professor Mary-Ann Knudstrup at the Department of Architecture, Design & Media Technology for guiding me through the process and providing critique.

I would also like to thank Associate Professor Tine S. Larsen for a good and beneficial collaboration with the measurements project of the Comfort Houses.

Furthermore, I would like to thank the PhD students at the Department of Architecture, Design & Media Technology and the coordinator of the ADPL group (Architecture & Design PhD Lab) Professor Ole B. Jensen for providing a discussion forum for research methodology and theories of science.

Finally, I would like to thank friends and family for their moral support through ups and downs. Most importantly, I would like to thank my fantastic Anders for his great patience, love and support. I could not have done it without you!

Summary in English

This PhD project is co-financed between Saint-Gobain Isover Scandinavia and Department of Civil Engineering, Aalborg University. The aim of the research is to investigate the notion of *passive houses in Denmark*. However, research and development of low energy buildings have been carried out in research environments for several years, those results have until now only limited been applied in practice. An exception is in Germany, Austria and Switzerland where the building concept passive houses have gained relatively big commercial success. When this PhD thesis was initiated, the Danish building industry has just started to become interested in the passive house concept, but the knowledge was very limited. To be able to speed up the process of constructing Danish passive houses or other low energy concepts Saint-Gobain Isover Scandinavia took the initiative to the pilot project of the Comfort Houses, ten single-family houses constructed as passive houses, and wanted to share the knowledge with the building industry and other interested. This PhD thesis was a part of the strategy.

If the concept of passive houses should be successfully promoted and achieve a significant sale in Denmark, it is believed that it is necessary to do a holistic approach. Besides energy savings and new structural solutions more qualitative aspects like architecture, everyday life and the future ways of living needs to be integrated in the future understanding of passive houses.

This Ph.D. thesis therefore studies the following research question:

What can the experience from the Comfort Houses enlighten about the future production and use of Danish passive houses?

This understanding is achieved through studies of different study fields to be able to create a more holistic understanding of the concept both covering qualitative and quantitative analysis. The main focus will be on the study fields *Design Process*, *Architecture and Everyday Life* and the *Indoor environment*, which will answer the following sub-research questions:

– *How has the consortiums behind the Comfort Houses approached the design process according to teamwork, method and tools? And what barriers and possibilities lie within the approaches?*

– *How do the occupants of the Comfort Houses experience the passive house architecture and the technical service systems? And has their everyday life changed by moving into a passive house? If so, how?*

– *To what extent do the Comfort Houses live up to a comfortable indoor environment? And how do the occupants of the Comfort Houses experience the indoor environment and the adjustment of it?*

In order to investigate those matters several kind of analyses based on several kinds of data, that has involved different kind of actors was necessary. The Comfort Houses has been followed from the first concept to the final design by participating in workshops with the consortiums and by interviewing the different consortiums in the project about the design process. Additionally, the construction process of the houses has been followed and at least twenty-five craftsmen from

the building site have been interviewed informal. Thousands of pictures have been taken and used to communicate the project. When the houses were finished and families moved in, they were interview about both how they experience the architecture, how their everyday life is in the house and how they experience the indoor environment. And the occupants' experiences were compared with measured data of the indoor environment, which evaluate both the performance of the house compared to the expected, but also the occupants' behaviour and understanding of the indoor environment.

The investigations have resulted in a list of recommendations that are important when designing future passive houses in Denmark. Firstly, the study indicates that the integrated design process is a beneficial approach for designing passive houses. But some circumstances are necessary to support the integrated design process like: actors in the design teams have to adapt expectations and agree about the aim and they have to establish an interest in each other's field of specialisations. Finally, it has to be possible to implement the different expertises in the project from the beginning of the design process.

Regarding the everyday life of the occupants, some have undergone changes after moving into the Comfort House e.g. curtain and/or blinds have become a part of the everyday practice of creating privacy in the house. And most occupants needed to get an awareness of the thermal environment and the use of curtains or blinds actively. Additionally, natural ventilation has become a permanent part of the everyday practices in the summer period to reduce excess temperatures. Information and knowledge about both the technologies and the way to act in a passive house (or any other low energy houses) is important for this concept to be a success both for the occupant and the environment.

The indoor environment is fairly comfortable in the houses, but there is still room for improvement. Especially according to the thermal indoor environment in the summer period and the reverberation time where the occupants experience discomfort, which is both a result of "poor" design and "wrong" user behaviour. Therefore the investigated areas need more focus in future design and construction of passive: sufficient analysis that can predict the indoor environment of the house in the process, greater focus on the occupants' life and behaviour, user-friendliness of the strategies, information, education and communication to the occupant about how to live in a passive house.

Comparing the different study fields show a high level of interconnectedness. An interconnectedness that are greater than we are used to, because the passive house is a different concept than conventional houses – mistakes and behaviour that goes beyond the planed will simple response much greater and either designers or occupants are used to that. This research has enlightened some of the significant areas to focus on when optimising the work with passive houses in Denmark. The findings will hopefully support a more holistic approach to future development of passive and low energy houses.

Summary in Danish

Denne afhandling er et sam-finansieret ph.d.-projekt mellem Saint-Gobain Isover Scandinavia og Institut for Byggeri og Anlæg, Aalborg Universitet. Formålet med projektet er at undersøge begrebet *passivhuse i Danmark*. I flere år har forskning og udvikling af lavenergibyggeriet primært foregået i forskningsmiljøer og resultaterne har indtil nu kun i begrænset omfang været anvendt i praksis. En undtagelse er i Tyskland, Østrig og Schweiz, hvor bygningskonceptet passivhuse har fået relativt stor kommerciel succes. Da denne ph.d.-afhandling blev indledt var den danske byggebranche kun lige begyndt at interessere sig for passivhus konceptet, men mængden af viden på daværende tidspunkt var meget begrænset. For at fremskynde processen med at bygge danske passivhuse eller andre lavenergi byggerier tog Saint-Gobain Isover initiativet til pilotprojektet Komfort Husene, ti parcelhuse bygget som passivhuse. Saint-Gobain Isover ønskede at vidensdele med byggebranchen og andre interesserede, hvorved denne ph.d.-afhandling var en del af strategien.

For at konceptet passivhuse kan opnå en betydelig succes i Danmark postuleres det, at det er nødvendigt med en holistisk tilgang. Udover energibesparelser og nye konstruktive løsninger, mere kvalitative aspekter såsom arkitektur, hverdagsliv og fremtids levebehov skal integreres i den fremtidige forståelse af passivhuse.

Dette Ph.d. projekt har derfor sat sig for at undersøgelse følgende forsknings-spørgsmål:

Hvad kan erfaringerne fra Komfort Husene afklare om den fremtidige produktion og anvendelse af danske passivhuse?

Dette kan besvares gennem studier af forskellige studieemner for at kunne skabe en mere holistisk forståelse af begrebet både kvalitativt og kvantitativt. Hovedfokus vil ligge indenfor emnerne *Designproces*, *Arkitektur og Hverdagslivet* og *Indeklima*, hvilket vil svare på følgende underforskningsspørgsmål:

- *Hvordan har konsortier bag Komfort Husene grebet designprocessen an i forhold til samarbejde, metode og værktøjer? Og hvilke barrierer og muligheder ligger inden for disse tilgange?*
- *Hvordan oplever beboerne i Komfort Husene passivhus arkitekturen og de tekniske systemer? Og har deres hverdagsliv ændret sig ved at flytte ind i et passivhus? I så fald hvordan?*
- *I hvor høj grad lever Komfort Huse op til et behageligt indeklima? Og hvordan opleve beboerne indeklimaet i Komfort Husene og tilpasningen af dette?*

For at undersøge disse forhold flere typer analyser baseret på forskellige typer data, der har involveret forskellige slags aktører var nødvendig. Komfort Husene blev fulgt fra den første idé til den endelige udformning ved at deltage i workshops med konsortier og ved at interviewe de forskellige konsortier i projektet om designprocessen. Derudover blev byggeprocessen af husene fulgt, og mindst femogtyve håndværkere fra byggepladsen er blevet interviewet uformel. Der er taget tusindvis af billeder, som er brugt til at kommunikere projektet. Efter husene

var færdiggjorte og beboerne flyttet ind, blev disse interviewet om både hvordan de oplever arkitekturen, hvordan deres hverdag er i huset, og hvordan de oplever indeklimaet. Samtidig blev beboerne erfaringer sammenlignet med det målte indeklima, som derved vurderer både husets præstation i forhold til det forventede, men også beboernes adfærd og forståelse af indeklimaet.

Forskningen har resulteret i en liste af anbefalinger, som er vigtige for udformningen af fremtidige passivhuse i Danmark. For det første viser undersøgelsen, at den integrerede designproces er en velegnet designmetode når der designes passivhuse. Men for at støtte den integrerede design proces er der dog nogle omstændigheder, som er nødvendige: aktører i designteamet er nødt til at afstemme forventninger og blive enige om hvilke mål de går efter, der skal etableres en interesse i hinandens fagområder og endelig skal det være muligt at indarbejde de forskellige kompetencer i projektet fra begyndelsen af designprocessen.

I forhold til beboernes hverdagsliv, har nogle gennemgået forandringer efter at være flyttet ind i Komfort Husene, f.eks er brugen af gardin og/eller persienner blevet en del af deres hverdagspraksisser for at skabe privatliv i huset. Derudover er de fleste beboere nødsaget til at være bevidste om det termiske indeklima og anvendelse gardiner eller persienner aktivt. Desuden er naturlig ventilation blevet en fast del af den daglige praksis i sommerperioden for at reducere temperaturen. Information og viden om både teknologi og måden at bruge et passivhus på er derfor vigtigt for at konceptet kan blive en succes for både beboerne og miljøet.

Indeklimaet er forholdsvis behageligt i husene, men der er stadig plads til forbedringer, især i henhold til det termiske indeklima i sommerperioden, og efterklangstiden. Det dårlige indeklima er både et resultat af "dårligt" design og "forkert" brugeradfærd. Derfor har de undersøgte områder behov for mere fokus i fremtidig design og konstruktion af passivehuse: f.eks. tilstrækkelig analyse, der kan forudsige indeklimaet i huset i designprocessen, større fokus på beboernes hverdagsliv og adfærd, brugervenlige strategier, information, uddannelse og kommunikation til beboeren om, hvordan de skal leve i et passivhus.

Det komparative studie af de forskellige emner viser en høj grad af indbyrdes forbundenhed. En forbundenhed, der er større end vi er vant til, fordi passivhus er et andet koncept end konventionelle huse - fejl og adfærd, der ikke følger det projekterede vil have langt større påvirkning på udfaldet end designere og beboere er vant til. Denne forskning har belyst nogle af de væsentlige områder at fokusere på, når fremtidens passivhuse i Danmark skal designes. Resultaterne vil forhåbentlig bidrage til en mere holistisk tilgang til den fremtidige udvikling af passive og lavenergihuse.

Tabel of content

1 Introduction

1.1 Background and motivation

This thesis grasps the notion of Danish passive houses, because it tuch upon a highly relevant subject in time of writing and because it has been the authors interest for several years – an interest in working with the challenge of fulfilling both stricht energy demand and designing high quality architecture without compromising the indoor environment.

This fits well with the resent years increased interest on sustainable, green, low energy, environmental architecture etc. It is a result of the need to focus on the future of our planet. The increasing CO_2 emmision in the atmosphere coursed by the increased use of fosil fuels is resulting in global warming of the planet. To be able to acommodate the problem something has to be done. The building industry in Denmark and the rest of Europe is therefore facing large challenges in fulfilling the EU directive of 2002 where new buildings and renovation projects need to improve the energy performance to be able to fulfil the Kyoto agreement from 1998 (Directive 2002). In Denmark it has resulted in new building codes according to energy use, which contains a classification of low energy buildings, which will be strengthened the following 5-10 years. By implementing tighter energy demands and energy labelling for existing buildings the awareness of energy performance groves and the energy performance of buildings become a competitive parameter. For the Danish building industry it means that they are facing new challenges both in developing new intelligent and holistic architectural building concepts but also new challenges for the manufacturer of products. Today the build environment accounts for about 40 % of the energy consumption in the EU and it is continuing to expand. It is a result of an effort to give the building users an optimum indoor environment by good ventilation, comfortable temperatures and sufficient light (Directive 2002). The level of energy consumption and the quality of the indoor environment in a specific building are very dependent on design and construction of the building envelope. Therefore to be able to fulfil the directive and to protect our environment we need to focus on new building concepts which both generate low energy consumption and a comfortable indoor environment.

Research and development of low energy buildings have been carried out in research environments for several years, but until now those results have only limited been applied in practice in common buildings both in Denmark and other European counties except Germany, Austria and Switzerland. Here the building concept “Passive houses” with about 80 % lower energy use than regular building work, have gained relatively big commercial success. Especially in Germany they have build thousands of passive houses and the concept is now very well acknowledged internationally and many countries are constructing houses that fulfil the passive house standard defined by the Passive House Institute in Darmstadt, Germany (www.passiv.de). In next paragraph the passive house concept will be further explained.

When this PhD thesis was initiated, the Danish building industry has just started to become interested in the passive house concept, but the knowledge was very limited. The concepts and building examples from Germany or Austria can not be copied directly to Denmark because the demands from the user and traditions in the building industry both according to architectural expression and the construction are different. So to be able to speed up the process of constructing Danish passive houses or other low energy concepts, research about this field is necessary. If the concept of passive houses should be successfully promoted and achieve a significant sale in Denmark, it is believed that it is necessary to do a holistic approach. Besides energy savings and new structural solutions more qualitative aspects like architecture, everyday life and the future ways of living needs to be integrated.

The goal of this Ph.D. study is to develop an understanding of how passive houses is produced and used in Denmark. This will primarily be done through studies of the project "THE COMFORT HOUSES", ten single-family houses build like passive houses (www.komforthusene.dk). This understanding is achieved through studies of different study fields to be able to crate a more holistic understanding of the concept both covering qualitative and quantitative analysis.

1.2 State of the Art of Passive Houses

In the following an overview of State of the Art within passive houses is outlines based on literature review.

The Passivhaus Institut was founded in 1996, by Dr. Wolfgang Feist, as an independent research institution. It employs physicists, mathematicians and civil, mechanical and environmental engineers, performing research and development on highly efficient energy use (www.passiv.de). The first demonstration project was build in 19991 and since then they have worked and are still work with the passive house standard as it is still being refined and expanded to other parts of the world than central Europe where it was developed. The term ‘‘Passive House’’ refers to a construction standard that can be met using a variety of technologies, designs and materials. It is basically a refinement of the low energy house standard. The standard has been named ‘‘Passive House Standard’’ because the passive use of secondary heat gains, which is delivered externally by solar heat gains through the windows and through internal heat gains from appliances and occupants (Schneiders 2006).

Table 1: The table shows the demand of fulfilling the passive house standard (www.passiv.de)

Space heat demand:	Maximum 15 kWh/year per m^2 net area
Primary energy demand:	Maximum 120 kWh/year per m^2 net area (incl. household)
Infiltration:	Air change at maximum 0,60 h^{-1} with a pressure difference of 50 Pa

The passive house standard consists of three requirements which has to be fulfilled, see Table 1. The idea behind the Passive Houses Concept is to create buildings with comfortable the indoor environment in both summer and winter without the need of a conventional heat distribution system. To be able to permit this, it is essential that the building's heating load does not exceed 10W/m2 which is roughly equivalent with an annual space heat requirement of 15 kWh/(m2a). This allow you to heat up the house with the ventilation air and then save the expense on conventional heat distribution system. Besides the three criteria there are some recommendations to a passive house. E.g. a very well insulated building envelope, orientations of the house to the sun and installation of a ventilation system with efficient heat recovery (about 80%) and more. Table 2 lists some of the recommendations (Schneiders 2006 and www.passiv.de).

Table 2: The table show basic features to have in mind when designing passive houses (www.passiv.de)

Compact form and good insulation:	All components of the exterior shell of the house are insulated to achieve a U-value the does not exceed $0{,}15W/(m^2K)$
Southern orientation and shade considerations:	Passive use of solar energy is a significant factor in passive house design.
Energy-efficient windows glazing and frames:	Windows should have U-factors not exceeding $0{,}08W/(m^2K)$, with solar heat-gain coefficient around 50%.
Building envelope air-tightness:	Air leakage through unsealed joints must be less than 0,6 time the house volume per hour.
Passive preheating of fresh air:	Fresh air may be brought into the house through underground ducts that exchanges heat with the soil. This preheat the fresh air to a temperature above 5°C, even on cold winter days.
Highly effective heat recovery from exhaust air using an air-to-air heat exchanger:	Most of the perceptible heat in the exhaust air is transferred to the incoming fresh air (heat recovery rate over 80%).
Hot water supply using regenerative energy sources:	Solar collectors or heat pumps provide energy for hot water.
Energy-saving household appliances.	Low energy refrigerator, stoves, freezers, lamps, washers, dryers etc. are indispensable in a passive house.

Other countries use the term "Passive Houses", but the definition are not exactly the same. In Switzerland the standard is also called "Minergie" and is closely in its definition to the German definition (www.minergie.ch/standard_minergie.html). In Sweden it is called "Passivhus". The requirement in this standard is divided into zones according to the latitude in the country. It means that the demand for the space heat is higher the colder the climate is (www.energieffektivabyggnader.se). The Danish building regulations has not defined a passive house category, but has defined low energy classes which gradually will over the years be implemented as standard requirements.

In the following an overview of previous and ongoing research about passive houses will be presented.

Figure 1. Examples of passive houses in Austria (private photos).

1.2.1 The CEPHEUS-project

One of the major studies of the passive house concept has been the EU-funded project of CEPHEUS (Cost Efficient Passive Houses as European Standard). The goal of the project was to construct and scientific evaluation of the operation of 221 housing units built according to the German passive house standards in five European countries: Germany, Austria, Switzerland, Sweden and France. The project wanted among others to demonstrate technical feasibility, study user behaviour under real-world conditions, test possibilities of implementing passive houses in several European countries and create the preconditions for broad market introduction of cost-efficient passive houses (Schneiders 2006).

The CEPHEUS project contained a comprehensive measurement project of the energy performance and the thermal comfort. Additionally some social research studies about behaviour, attitude and the satisfaction of living in a passive house were recorded. These studies were carried out mainly as questionnaires and as a longitudinal study meaning that the questionnaires was carried out over time. The conclusion on the project was that 80% of the space heat consumption could be saved in a passive house and the total primary energy consumption was lowered with 50% compared to a conventional new building. According to the social studies the passive houses was a success and the tenants were highly satisfied. Therefore the report concluded that the development of passive houses should be disseminated to a large scale (Schneiders 2006, Feist at al. 2001 and Danner 2001).

The report also concludes that there are some barriers for the passive house to gain more of the market share. To have success on the marked the passive houses should have “comparative advantages” according to other buildings and these advantages have to be acknowledged by architects and customers and not just scientists. Additionally, buildings belong to the “experienced goods” where positive experiences with houses need a period of time to become a general perception. Often people relies on experiences of friends and family, therefore there have to be a series of building projects which have been experienced. In Germany, Austria and Switzerland the passive houses have been grooving a lot and it is believed that the success story of the first passive house in Darmstadt from 1991 is one of the causes. The project was documented in great detail and fulfilled the theoretical predicted advantages and the knowledge was spread among the relevant groups (Schneiders 2006).

1.2.2 Experiences from Swedish passive houses

In Sweden, they started to build passive houses earlier than in Denmark, the first passive house was finished in 2001, ten years after the first passive house in Germany. More houses has been build and several researches have been done especially at Lund University. In the following some of them will be outlined.

PhD fellow Ulla Janson is doing a four year research project about passive houses. She has finish a licentiate thesis describing the results from the early planning and design of Swedish passive houses to final construction of four passive house projects. During the last two years of the PhD period, more detailed analyses will be carried out of the four projects regarding energy performance, comfort and occupancy aspects. The expected results are to find guiding principles and tools needed for passive house planning and make the system solutions usable for planning in more general terms (Janson 2008). The results of the licentiate thesis show that the project leader has a key role, but it is still possible to build passive houses with good results even if the project leader does not lead the project perfectly. Well defined goals have to be followed throughout the process. Lack of good leadership might not affect the final result, but it affects the final cost. It is expensive to make correction and changes at a late stage in the project. Additionally to get a larger production of passive houses in Sweden, more components suitable for passive houses need to be available on the Swedish market such as low energy windows and doors, more types of heat exchangers and maybe integrated with a heat pump and more (Janson 2008).

Figure 2. Pictures of the first passive house project in Sweden – row houses in Lindås Park in Gothenburg (www.passivhuscentrum.se/lindas_ radhus.html).

The two following research works look at the first passive row houses in Lindås Park in Gothenburg. The first research work is a multidisciplinary work which had several focus – social, technical and socio-technical. It included aspects like the construction process, the user behaviour and opinion about the house, indoor environment, ventilation systems, windows etc. investigated through various methods like interviews, measurements and minutes. Some of the conclusions in the report are: the occupants thrive in the houses and the layout of the unit fits them. But, in the homes with few occupants, they struggle to stay warm. Many occupants also experience different temperatures between the floors, which for some occupants is a large problem. The solar panels do not delivered the expected amount of energy and they have trouble with overheating in them in the summer period. Finally, many of the occupants ask for more user-friendly manuals to the technical systems, which the report state would result in lower energy use (Boström et al. 2003).

Charlotta Isaksson also took part in the above report but her final PhD thesis focuses more on the domestication of how to handle the technologies in the passive house based on the occupants' previous knowledge. Therefore she has conducted more interviews to register the learning processes with the technical installations over time as they lived in the passive house. The objective was to find out how the occupants use, choose and relate to the technique of the heating and ventilation in the home, with the focus on domestication. The results were that some occupants were very committed to learn the technologies in the houses, but others were also afraid of it. Gradually, the occupants got more confident with how to manage the heating in the passive house. The occupants had to learn how to manage the variations in temperature in connection to e.g. sun and visitors as it is important to know the limits and possibilities of the heating and ventilation technique (Isakson, 2009).

1.2.3 The first certified passive house in Denmark

Before the project of the Comfort Houses, the knowledge about passive houses was limited in Denmark. One man – an architect originally from Germany called Olav Langenkamp, build his own house as a passive house according to the German passive house standard from the Passive House Institute in Darmstadt, se Figure 3. He had a challenge both according to the local plans which only allowed one story building, which results in bigger surface area of the building and challenges because the building had to be orientated to south west because of a outstanding view. It went well with the detailing of the project, but according to lowering the cost he had to use a German contractor. Some parts like plumbing, electrical installations etc had to be done by Danish contractor. This resulted in very time consuming coordination between Danish and German firms. With this project he showed that it is possible to build passive houses in Denmark at a reasonable price (Langenkamp 2008).

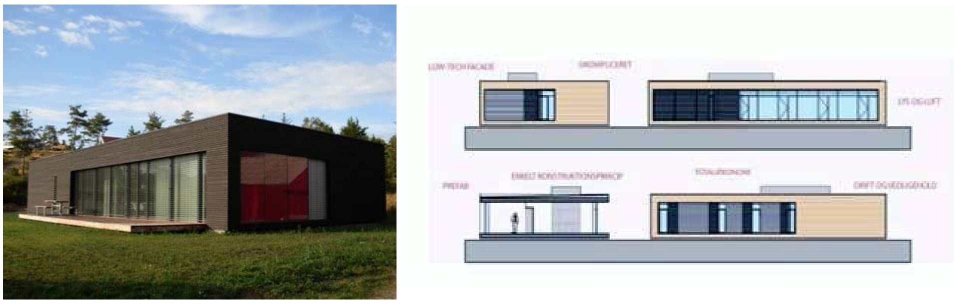


Figure 3. The first certified passive house in Denmark occupied from 2008 (www.passivhus.dk).

1.2.4 Understanding of Danish Passive Houses based on Pilot Project Comfort Houses

...is the title of this PhD thesis. As mentioned in the beginning the building codes are being tightened in the next 5-10 years and to be able to fulfil those demands and design attractive and well functioning dwellings we need more knowledge. We cannot copy the passive house concept directly to Denmark from Central Europe, because the demands from the user and traditions in the building industry both regarding architectural expression and the construction are different. The building industry needs to find its own Danish approach. Until now we have seen more fragmented research about specific aspect or technologies of passive or low energy houses e.g. development of renewable energy sources, low energy windows or efficient heat recovery systems, but a more board view of the concept is also necessary. It can reveal how the passive house concept and the technologies work in practice and how the users experience them in their everyday life. A satisfied user is important – if not the most important success criteria to get the marked dedicated to the passive house concept. The earlier mentioned projects and research about passive houses is therefore not sufficient enough to understand how to approach Danish passive house. The project of the Comfort Houses is an ideal case study to be able to understand the development of Danish passive houses.

1.2.5 The project of the Comfort Houses

Saint-Gobain Scandinavia was the initiators of the project the Comfort Houses. In collaboration with Zeta Invest and Middelfart Savings Bank (Middelfart Sparekasse) it became possible to construct ten Comfort Houses as passive houses according to the German passive house standard (www.komforthusene.dk). The Comfort Houses was considered as a pioneer project that would show the Danish building industry an example of how to achieve the objectives of the Kyoto Protocol within the market terms. Knowledge and expertise would be assembled and disseminated out to the building industry. The project wanted to show ten different examples of single-family house, which both helps to reduce the CO_2 - emissions and has an optimum indoor environment. In addition, the goal was to raise awareness of the houses with passive heating and thus set the agenda for future constructions and debate the energy policy. The project involved a wide range of stakeholders, both engineers, architects, contractors and manufacturer and served as a learning process of both them and the rest of the building industry which followed from the side (www.komforthusene.dk).


Figure 4. The eight passive house certified Comfort Houses

The idea with the project was to find ten different consortiums consistent of both architects, engineers, contractors (and in some cases also manufactures) to design and build each their house. The initiators posted some criteria for both the consortium and the construction. The consortiums had to be willing to enter a multi-disciplinary teamwork and willing to put their own paid innovation available for the project. The requirements for the house covered both interior and building envelope in terms of U-values, energy requirements, quality, time schedule and economy. Furthermore the initiators expected the consortiums to design a house with a good indoor environment. For more information about the project go to the webpage www.komforhusene.dk or the tender document in Appendix C. A brief introduction to the different houses can be found in chapter 3 and in the Danish book about the Comfort Houses developed during the project *Komfort Husene – Erfaring, viden og Inspiration* (Komfort Husene 2010).

Through the project period there was organized several workshops where all the consortiums met and discussed different issues. Experts were also involved and a high degree of knowledge sharing took place. During the construction period several events on the construction site took place. All interested was invited and there were presentations and tours around in the houses, more than 3000 people have visited the site.

During the process the global financial crisis came in 2008 and the Comfort Houses was also affected. The construction of two houses were stopped because some actors in of the consortiums went bankrupt. Additionally the initiators hoped to sell the houses in the fall of 2008, but because of the financial crisis the housing market was not very active. In the spring and summer of 2009 the owner, Komfort Husene A/S, instead began to rent out the houses and they managed for some of the houses within the timeframe of this thesis.

1.3 Aim and research question

Besides meeting the energy goals of the future, it is still necessary to create homes that are complete solutions, which also covers indoor climatic requirements and more functional and qualitative areas, if they should be future-proof and saleable in relation to the buyers and their needs. Therefore knowledge and experience about the architecture, building technique, indoor environment, user behaviour and user needs are studied to hopefully get a more holistic approach to future Danish passive houses. The resulting knowledge should be helpful for the design teams and clarify both what they do and why they do it.

The overall research question is therefore:

What can the experience from the Comfort Houses enlighten about the future production and use of Danish passive houses?

To answer that the following study fields are examined: The *Design Process*, the *Construction Process*, *Architectural Expression and Building Technology*, *Architecture and Everyday Life* and the *Indoor environment*. Ideally all listed study fields should be studied to achieve a more holistic understanding of passive houses in Denmark and some might be missing like economy or politics, but a limitation is necessary to fit the research within the timeframe. Figure 5 shows how the study fields are connected and has an influence on each other. The design process for example defines what to build and how to build in the construction process. Then the occupants move into the house with their everyday life. Finally, the operation of the houses results in an energy use and an indoor environment. It is believed that it is possible to suggest how to approach passive houses holistically in the future by giving some of the study fields less focus. It is still possible to understand the connection between the design decisions made in the design process and the architecture and everyday life of the residents, without an in-depth analysis of e.g. the construction process.

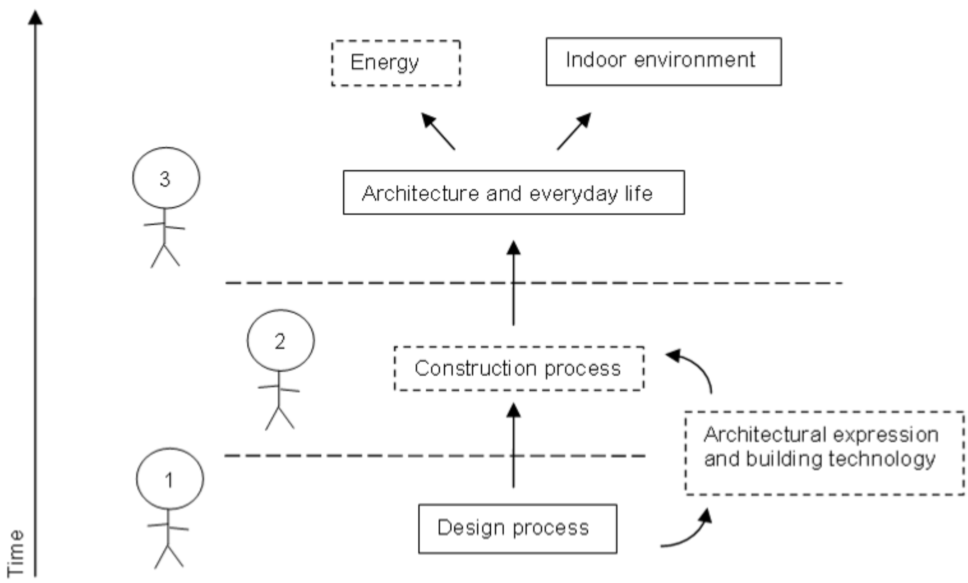


Figure 5: The illustration shows the different study fields and how they linearly take place in time. The matchstick man illustrates how the different study fields involve different main actors.

All study fields will be touched upon, but the main focus will be on the *Design Process*, *Architecture and Everyday Life* and the *Indoor environment*. Therefore following sub-research questions arise:

– *How has the consortiums behind the Comfort Houses approached the design process according to teamwork, method and tools? And what barriers and possibilities lie within the approaches?*

– *How do the occupants of the Comfort Houses experience the passive house architecture and the technical service systems? And has their everyday life changed by moving into a passive house? If so, how?*

– *To what extent do the Comfort Houses live up to a comfortable indoor environment? And how do the occupants of the Comfort Houses experience the indoor environment and the adjustment of it?*

2 Methods and Theory of Science

2.1 Case studies and study fields

The research design is defining the frame within the data is collected and analyzed and in this research project the design is a case study design. Single case studies are often being criticised for not being able to generalise, but case studies should no be compared with e.g. surveys, which relies on statistical generalisation. A case study has to be seen as a kind of experiment, which relies on analytical generalisations. A particular set of results is use to state a broader “theory” about the phenomenon (Yin 1995). The ten Comfort Houses and the actors connected to them represent a case in this research project. The actors are the consortium, the craftsmen and the occupants. A case study can have different designs depending on the type. The Comfort Houses are investigated according to five different study fields and can therefore be defined as an embedded multiple-case design according to Robert K. Yin´s matrix, Figure 6. Multiple cases are often seen as more compelling and robust, but at the same time a single case design cannot be satisfied with a multiple case design, because is often is a rare or critical case. Moreover, the multiple case study design is often more time consuming – it equals that one should make multiple scientific experiences (Yin 1995).

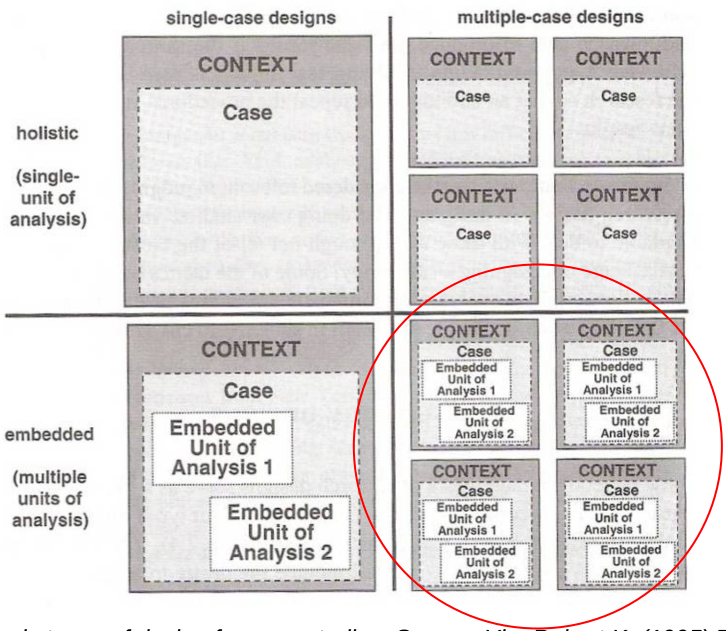


Figure 6. Basic types of design for case studies. Source: Yin, Robert K. (1995).The approach for this research project is outlined with the circle.

Each study field (a unit of analysis) is carried out as a comparative study cross cases and is studied by using identical methods to be able to compare them, and by that seek explanations for similarities and/or differences and gain a greater awareness and deeper understanding of the field. The embedded multiple-case design also has pitfalls. It can occur when the case study focus only on the level of the individual study fields and fail to return to the lager unit of analysis (Yin 1995). It means that the analysis of the individual case is studied cross study fields, to seek for any red thread or patterns for the particular case and the project as a whole (Figure 7).

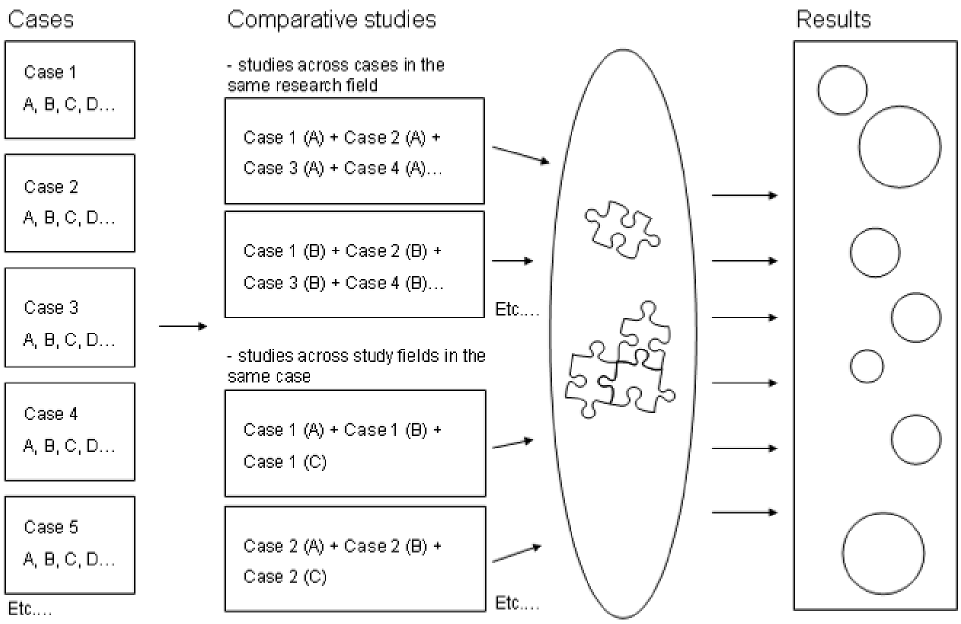


Figure 7. The illustration show how the different research fields are compared. A, B, C, D etc. have to be understood as the different research field in the project.

In the following all the study field of this research will briefly be described.

Design Process

The design processes behind the ten projects is investigated through interview with the ten consortiums. The objectives of this research are to clarify the different design processes according to method, tools and teamwork. This knowledge can tell something about how to approach future projects with passive houses in Denmark.

Construction Process

The construction process will be documented by weekly visits to identify new challenges, possibilities and/or problems that will occur when building passive houses. It will be documented by observations, photo documentation and informal interviews with the craftsmen: carpenters, bricklayer, roofers etc. but also with the contractors, site managers, engineers and architects.

Architectural Expression and Building Technology

Through the experience with the development of the Comfort Houses it is discovered how the solutions in a Comfort House influence the traditional way of designing a single-family houses and how it influence the Danish architecture. It is also studied how selected building technical areas of a passive houses can influence the architectural expression. It will clarify important aspect to be aware of according to the architectural expression and the building technology when designing passive houses to avoid compromising either aspect.

Architecture and Everyday Life

The starting point is the new trend which involves a shift in relation to our perception of leisure, work-life and private life, where the boundaries are fuzzy and demands new requirements of our houses. With the core values based in the future which consists of concepts such as flexibility, complexity, interaction and subjectivity, the people should be seen as a subject in a complex world that is constantly under influence and change. This affects both the physical requirements of the dwelling e.g. connection between spaces, room sizes etc. but also affects the softer aspects such as the dwelling's influence on the everyday life that exists in the house. The resulting everyday lives of occupants in the ten Comfort Houses are examined to document the possible consequences of living in passive houses. It means it examine how the dwelling is used and whether it fulfils the wishes of the occupants to house. Furthermore, it will examine whether the occupants have changed the behaviour or habits in the new house and if it is something they can live with. This knowledge would thereby clarify the possible barriers and possibilities of living in passive house and provide knowledge for future passive houses in Denmark.

Indoor Environment

The indoor environment will be analysed through practical measurements and qualitative interviews with the occupants about their perception of indoor environment. The measurements (which are a part of a 3 ½ year measurement project supported by Realdania (www.realdania.dk) and led by Tine S. Larsen, Aalborg University (Demonstration project 2009)) are compared with the analysis of the interviews with the residents, to determine if there are agreements and in some cases explain the reason for certain measured results. This knowledge can therefore be used to evaluate whether the Comfort Houses improve the experience of the indoor environment, and in what sense.

The project of the Comfort Houses original started with ten housing proposals, but because the project was affected by the global financial crises it resulted in change of contractor in two of the houses and because of different circumstances they could not be certified as passive houses. Additionally, the houses were supposed to be sold on the regular housing marked, but again because of the financial crises it was not possible. Luckily the owner of the houses managed to rent out some of the houses and most of the occupants wanted to participate in this research work. Each house represents a case and Table 3 gives an overview of the amount of cases creating the foundation of the different study fields. The cases will not be combined with the actual house, because both the consortiums behind the design of the house and the occupants have been promised anonymity.

Table 3: Overview of the main study fields and respective cases in the analysis.

	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8
Design Process	x	x	x	x	x	x	x	(x)*
Architecture and Everyday life		x					x	x
Indoor environment		x					x	x
*The study of the design process has been carried out in case 8 but because it was the second design of a Comfort House from this consortium, the results have been taken out. The process did not have the same preconditions as the other cases.								

2.2 The use of different methods

In a case study design both qualitative and quantitative methods can be used, which means that many kinds of data can be collected through e.g. interviews, surveys, observations, documentation etc. (Yin 2005). This is also the situation in this research project. In some literature this approach is called mixed methods (Bryman 2008). Previous some researchers argued that it was not possible to combine qualitative and quantitative methods because a) the embedded methods are not feasible or even desirable. They argue that the two research strategies provide different procedures and therefore different epistemological implications. b) The other argument is that qualitative and quantitative research belong to each there paradigm and according to Kuhn, paradigms are incommensurable. Since the 80´s the argument for combining research has increased. There are areas of overlap and shared aims between qualitative and quantitative research and the paradigmatic war is almost over (Bryman 2008). Today you find more publications about the subject e.g. Journal of Mixed Methods Research and more general publications about mixed method in social research e.g. by Alan Bryman (Bryman 2008), Abbas Tashakkori and Chales Teddlie (Tashakkori et al 2009). In research done by Alan Bryman the argument of using mixed methods can be different. He developed different categories of mixed methods approaches e.g. *Triangulation*, *Completeness*, *Explanation*, *Credibility*, *Illustration*, *Utility*, *Enhancement* etc., were research work often can cover more categories (Bryman 2008 and Bryman 2006).

To answer the research questions in this thesis, mixed methods are essential. Even though the publications mentioned above focus on mixed methods in social research e.g. questionnaires and/or statistics vs. interviews and/or ethnography. It is believed that mixed methods terminology also covers qualitative social research methods and empirical analytical methods of natural science, like measurements, and calculations/simulations. Based on Alan Bryman´s definitions the mixed method approach in this project can be categorised in the following categories:

Completeness: refer to the notion that the researcher can bring together a more comprehensive account of the area of enquiry in which he or she is interested if both quantitative and qualitative research are employed.

Diversity of view: This includes two slightly different rationales – namely, combining researchers' and participants´ perspective through qualitative and quantitative research respectively and uncovering relationships between variables through quantitative research while also revealing meaning among research participants through qualitative research.

Illustration: refer to the use of qualitative data to illustrate quantitative findings, often referred to as putting "meat on the bones" of "dry" quantitative findings.

Utility: or improving the usefulness of findings – refer to a suggestion, which is more likely to be prominent among articles with an applied focus, that combining the two approaches will be more useful to practitioners and others. (Bryman 2008)

The combination of qualitative and quantitative methods can give more nuanced result of the investigated issues. An example could be: Measurements of the indoor temperature in a room show too low temperatures 25% of the time. The measurement can not give the answers to why the temperatures are too low? Unless we for example have observed that the window has been open, we could suggest that to be the reason. The observation and the measurements only explain how the situation is, but cannot tell why e.g. the window was open. The researches can have some suggestions, but they are based on his/hers previous experiences and not based on empirical scientific work. If the researcher needs to know why, he/she has to step into another approach – a qualitative approach e.g. involving the occupants of the room who might give the explanation of the open window. This combination of knowledge will give a more holistic understanding of how to achieve comfortable indoor environments in practise where user-behaviour and user-understandings are taken into account. The qualitative interviews and quantitative measurements are juxtaposed in a comparative study. The research project *"Indoor Environment and Quality of Life"* at the University of Southern Denmark is an example of where qualitative social research methods and empirical analytical methods of natural science have been combined in practise (Jaffari et al 2009). One concern of the project is to investigate people's notion of comfort. This is done by conducting ethnographical field studies in people's life parallel with collecting measurements of comfort parameters like temperature, light, humidity and CO2 levels. The study shows that the occupants' behaviour not necessary reflects the building standards' notion of comfort. The study therefore suggests: *"The concept of comfort has to be expanded to include not only physical factors, but also, psychological, behavioural and mundane, situational ones"* (Jaffari et al 2009). The study could not have come to this statement with only one perspective – it was necessary to use both qualitative and quantitative methods.

In the following the different methods used in this research will shortly be outlined.

Table 4 shows in which study field the methods have been used and combined.

Table 4: The different methodical approaches are listed by the different study fields.

	Design process	**Construction process**	**Architectural expression and Building Technology**	**Architecture and Everyday Life**	**Indoor environment**
Method(s)	Interviews	Informal interviews Observations Photo documentation	Calculations/simulations	Interviews	Measurement Calculations Interviews

2.2.1 Qualitative interviews

In some study fields qualitative interviews are used because the aim is to understand the person or group of people's life-worlds.

"…interviews are especially suitable when investigating people's understanding of the meanings in their life-worlds, describe their experiences and self-understanding and clarify and elaborate on their own perspective on their world" (Translated from a Danish edition, Kvale 1997, b: 111).

The qualitative interview varies from the quantitative interview e.g. questionnaires by being more flexible because it allows the interviewer to ask new questions that follow up on the replies or change the order of the questions according to the progress of the conversation. In a conversation new insight, that has relevance for the research, can appear and the qualitative interview makes it possible to follow up with extra question on relevant topics that occur. A conversation also allows dialogue to achieve a common understanding of the discussed and the interviewer can change or clarify the questions if the interviewee does not understand them etc. A quantitative interview on the other hand needs to be more standardized, because the idea is to be able to e.g. make statistics or generalise the findings. In a qualitative interview the goal is not to generalize, but to get a contextual understanding of the phenomenon. However some researchers makes moderatum generalisations, which means the focus of the research can be seen as instances of a broader set of recognizable features (Bryman, 2004 and Kvale 1997).

Most of the interviews are carried out as focus group interviews. The advantages of focus group interviews instead of one-to-one interviews, are first of all that the interviewees are able to probe each others point of view, which can make people think of something they in a one-to-one interview would not have thought of and people are able to modify or qualify their view, which can bring wider views to the investigated topic. The fact that the interviewees argue with each other and challenge each other can result in more realistic opinions, because they are forced to think about their views and maybe revise them (Bryman, 2004). The weakness with qualitative focus group interviews are e.g. some participant might hold back their own opinion, because they are conflict-averse or e.g. in the case of the design process the consortium think of their company's reputation and want to give a good impression of their firm. Other things the interviewer has to be aware of when using the qualitative interview are e.g. the lack of transparency in the investigation. It can be difficult to see what the researcher actually did and how he/she got to the conclusions. The reader is dependent on the researcher's selection of statement and the context they are placed in. Another thing is the understanding of what is being said both during the interview situation and later in the transcribed interview. It can be essential what the interviewer thinks the interviewee means by a certain phrase or term. Therefore it is important during the interview to sum up what has been said or ask about the meaning for the interviewees to confirm or clarify. Other ways of controlling the analysis is to use more researchers in the analysis of the same interview. It can lead to richer analysis and clarification of terms. Another solution is to present examples of the material and careful account for every step in the analysis process (Bryman, 2004, Kvale 2007).

The procedure of the semi-structure interviews in this research project is first to develop a semi structured question guide. It is divided in sections with the themes interesting for the investigation, see examples in Appendix D. The interviews are recoded on a Diktaphone, then each interview is transcribed and analysed individually and summarized in a report. One of the reports are published together with the question guide in *"Interview Report about the Design Processes behind the ´Comfort Houses´"* in Danish (Brunsgaard 2009a). The transcription in the project has not been a full detail transcription, but had character of a detailed summery. The reason is that the data analysis software Nvivo (www.qsrinternational.com) has been used to structure the entire interviews in the project and the analysis can be done directly on the soundtracks. The Nvivo software is also very suitable when working with case study, because all data can be combined in one program and analysis can be performed both on the individual case or study field, or you can make cross analysis. The program speeds up the analysis phase because the thorough transcription can be skipped and the overview of all the cases is better when analysing. When making the interview for study field *Design Process* pilot-interviews were made to test the question guide and get a fundamental knowledge of the field before performing all the interviews. It resulted in changes in the question guide that made the interview flow better. Later a follow-up interview was made with same case. To the study of the design process a statement of consent was made to make sure that the interviewees participated voluntarily and could leave when they wanted and that they had anonymity. This was not made with occupant in the houses when studying the *Architecture and Everyday Life* and the *Indoor environment*. It was evaluated that they would feel a statement of consent would be intimidating and signal it would be something risky. In stead it was based on the concept of dialog (Kvale 1997). It means they are informed by the research, its goals and of course promised anonymity.

The interview in the study of the *Construction process* had a little different approach. The interviews were of informal character, because most of the craftsmen do not have the time for long interview sessions and it can be difficult to collect all craftsmen at one meeting, because they are not necessary on site at the same time and some are only there for at short period of time. One-to-one interviews would be too comprehensive for this analysis. Additionally, the informal intervies was selected because the study of the construction process had a minor focus in this research project. Again there was no statement of consent because the interviews had character of field work, where it is not desirable, because it is important to follow “unexpected” traces (Kvale 1997). The interviews were memorized by the interviewer during the interview and afterwards written down. It is believed that the best answers are given while they are actually performing their work and it is possible to support the interview with photo documentation. The interviews were not recorded on Dictaphone because it was judged that it could be transcendent to speak into it and they could hold back information because of shyness. The drawback could be that the interviewer has forgotten details of the interview when writing it down. It turn out not to be a problem, because it was easy to ask the craftsmen again if it was necessary since most of the craftsmen were there several days during the construction period.

2.2.2 Observations

The method of observations was used in the study field *Construction Process*, which had character of field work. Observations were conducted together with the informal interviews with the craftsmen. The observations was written down together with the notes of the interviews and supported with photo documentation. This method will not be further discussed because the construction process is not a main focus in this research project.

2.2.3 Measurements

The study field of *Indoor Environment* is based on the methods of both qualitative interviews as described above, and on quantitative measurements of the indoor environment. A distinction is made between continuous measurements, which are made every fifth minute throughout the measurement period (3 years), and spot measurements, which are made during visits in the houses. The continuous measurements are: temperature, CO2, and relative humidity (RH) - in a bedroom, master bedroom (only in some cases), living room, kitchen and bathroom. The focus will be on the living room and bedroom. In some analysis other rooms are used to illustrate similarities or differences. The bathroom measurements will not be touch upon in this paper. Spot measurements are: Daylight factors in the living room and reverberation time and noise from the ventilation system in living-kitchen area.

Thermal comfort

The thermal comfort and indoor air quality is evaluated by using the guidelines set out in CR 1752 (CR 1752). The houses should meet category B in CR 1752 as a minimum.

Daylight

Daylight is evaluated by the demands in the Danish building regulations paragraph 6.5.2 , which says:

"Working areas, occupiable rooms in institutions, teaching rooms, dining areas and habitable rooms must have sufficient daylight for the rooms to be well lit. Windows must be made, located and, where appropriate, screened such that sunlight through them does not cause overheating in the rooms, and such that nuisance from direct solar heat gain is avoided." (BR08)

In evaluating the results a daylight factor of 2% will be used as a minimum limit of the daylight factor. The measurement method follows the instructions in the SBI instruction 219 (Johnsen et al 2009). The daylight factor is only measured in the common rooms.

Noise

The evaluation of the measurements of noise from the ventilation system and the reverberation times in the living room have been based on DS490 (DS 490), because the building regulations (BR08) refers to the function requirements in that. Even though the demands in BR08 are minimum class C, the demand in this evaluation is set to class B, because of the formulation of the demands in the tender document:

"Consideration must be given to the building's sonic capabilities of the project, so the house appears as a comfortable house to live in. Here should especially the reverberation be taking into account. All construction joints, installations and penetrations must also be soundproofed" (translated from Danish).

This formulation equals the formulation of class B in DS490, since the building regulations.

2.3 Theory of science

As mentioned above different methods are used in the process of collecting knowledge and experiences from the Comfort Houses because architecture can be divided into two parts; the measurable and the immeasurable. It means the project both takes qualitative approaches based on subjective sources of information, and quantitative approaches based on objective sources of information. Scientifically these two approaches are founded on two lines in the scientific field: natural science and social science. In the following a brief overview of the approach is presented. More details can be found in *Understanding of Danish Passive Houses based on Pilot Project the Comfort Houses*, in Jensen, O. B. (ed.) (2010) *Design Research Epistemologies I – Research in Architectural Design*. Brunsgaard, C. (2010), Aalborg: Department of Architecture, Design and Media Technology, pp. 61-78, ISSN: 1603-6204 (Appendix A).

2.3.1 Different scientific positions

Natural science is based in the empirical analytical scientific approach and has been dominating since the 1920´ies. At that time there were a clear distinction between objective and factual knowledge on one side and the subjective norms and values on the other side. The clear distinction was later doubted and resulted in different kinds of empirical analytical approaches, but generally empirical analytical scientists are focused on what is positively given and sticks to the verified sayings and refrain from emotions and opinions. The development in the empirical analytical approach today is not so much to set up specific normative instructions for how research should be done, but more to achieve an image of what research is as correct as possible (Andersen 1994). But what is empirical analytical science? In the empirical analytical field is the object taken out of its natural environment and idealised – it becomes an artefact. It means you will leave out elements which is not relevant to the “experiment”. Yet there can still be different ways to outline or define boundaries for an object, not of empirical character but founded in the ontological assumptions. An experiment presupposes a theoretical frame for it to be interpreted and often the ontology lies implicit within it. Generalisation based on empirical findings (specific level) or principals (general level) can be understood as theories and becomes preconditions for the scientific work (Kragh 1991).

Social science on the other hand is often more subject orientated and often uses qualitative methods because they are good to discover new fields of knowledge and can tell something about people’s motives of actions. In this field we find among many others the phenomenological and the hermeneutical approach. (In the following the discussions will limit to these two approaches of social science, because the goal with this chapter is not to describe all scientific approaches). When working with qualitative methods it is important to be aware of what scientific field you place your self in, because they have different ideas of how the human acts, it differs what part the scientist plays and you need different qualitative methods and analysis which also produce different kind of knowledge (Jacobsen 2008).

The phenomenological and hermeneutic approaches both have similarities and differences. They both take off in the individual. An individual that can think, feel and act independently, which thereby influence the social life. These approaches also have in common that they concern about why people do, think or act as they do and not just what they do. The phenomenological and hermeneutical approaches differ by the way knowledge is understood. In hermeneutic you want to understand the part in connection to the whole, meaning that the data have to be understood in connection to the context it is produced in. The data do not speak for it self; it has to be interpreted in its context to make sense. Therefore the researcher itself and his/hers pre-understanding becomes an important part of the findings. In phenomenology the phenomenon is studies on the basis of how the individuals experience reality. The phenomenon does not need to be interpreted but can be described and understood out of how the individual experience them. Therefore the researcher needs to step back and be an objective observer and his/hers opinion should not be put in action (Jacobsen 2008).

2.3.2 Scientific position(s) in this Ph.D. thesis

The study fields of this Ph.D. can not be positioned in one scientific position, because they are founded in theories that are based in different scientific positions – eclecticism. In the following the scientific position of each study field will be described and discussed, see also Table 5.

The theories behind the passive house standard are based in the empirical analytical field as it is founded in generalisations based on empirical findings and principals (Kragh 1991) related to scientific work of indoor environmental and energy engineering. These principals is enlighten through national and international standards. That way different "experiments" or in this case calculations of buildings energy use can be produced or reproduced and be compared.

The study of the *Architecture and Everyday life* wants to find out how the residents experience the architecture of the passive house and want to know if these types of houses affect the everyday life in the house, and in that case how it affects it. A hermeneutic approach would contain an interpretation of the statement (the part) in relation to the context (the whole) to be able to generate insight. An example could be that a resident thinks he feels too exposed in the house because of the big windows to the south. To able to understand why he feels too exposed we need to understand the context. The context could be several e.g. the culture, the society, the background or even the childhood of the resident and more. Additionally the researcher has to take his or hers own pre-understanding into account. In a hermeneutic approach there is not one truth or result, it is more a process where more and more interpretations will cover the field better and better (Jacobsen 2008). The outcome of a statement often leads to more comprehensive description than the original statement (Kvale 1997). In the phenomenological approach on the other hand it is interesting to find out how the phenomenon appear and manifest itself based on how people experience them. Often architecture and the life inside is something you sense and experience and the phenomenological approach will produce knowledge that describes experience as unprejudiced as possible. Alfred Schutz created with a conceptual universe a phenomenological foundation for how to use everyday life as a basis of the analysis of the social life. Others like Birte Bech-Jørgensen also followed that line. The actions that people (or the residents in this case) do in their everyday life on the basis of their consciousness of the everyday life are full of information about how the social life functions and are appointed. Alfred Schutz and Birte Bech-Jørgensen work with the term inter-subjectivity which is what is common and general for various individuals (Jacobsen 2008 and Jørgensen 1994). The results are often a condensation of the original statement which still makes sense for the people in their everyday life based on their opinion about their actions (Kvale 1997). Therefore a scientific position in phenomenology would in this study field about the *Architecture and Everyday life* create knowledge that can be used and understood by other individuals than the ones involved. More knowledge about the theoretical basis in everyday life studies can be found in the theoretical chaper in the article *Occupant Experience of the Everyday life in some of the first Passive Houses in Denmark*. Brunsgaard, C. et al. (2010c). I : Housing, Theory and Society.

By studying the *Design Processes* you should at least be aware of what scientific position you, as a researcher, have to the research field, but it is also worth to be aware of what scientific field the artefact you study moves around in.

Let us start to look at the scientific field of the artefact. Two design processes will never be the same and sometimes they actually need to be different – it depends on the project. Each project has individual goals and demand and different design teams have different experiences and knowledge. It means that the theoretical understanding of the design processes do not necessarily take-off in the same theoretical position or balance between theories (knowing that rarely a design process is looked upon theoretically in practice). Looking at the theory behind the integrated design process (Löhnert G et al. 2003 and Knudstrup 2004), it wants to combine both technical and architectural aspect at the same time in the process. The balance between the fields will as mentioned before vary according to the scope of the project – a factory and a dwelling will generally not aim at the same architectural or technical level, but still both fields are in play at the same time. If we look at the traditional design processes, which is a more linear process (Brunsgaard et al 2010b), each scientific understanding takes care of each their field. It means that the design process is looked upon by one set of "glasses" at a time. The scientific approach in the integrated design process is therefore to constantly switch between the empirical analytical and the phenomenological "glasses".

The scientific position to this study field is to stand on the side and study the artefact – the design process. It results in findings of where the different artefacts are positioned according to the different theories of design processes. The results will be unprejudiced descriptions as possible of how the design team experiences the phenomenon – the design process. The scientific position in the research of the design process is phenomenological.

Table 5: The theory input, methodology and epistemology of the different study fields in focus in the thesis.

Study fields in focus	**Theory input**	**Methodology**	**Epistemology**
The design process	The traditional and integrated design processes	Interviews	Phenomenological
Architecture and everyday Life	Everyday life theories	Interviews	Phenomenological
Indoor environment	International standards	Measuring/ calculations Interviews	Empirical analytical Phenomenological

The study field about the *Indoor Environment* and *Building Technology* is originally founded in the empirical analytical field, but we see a bigger and bigger interest in viewing the fields of energy and indoor environment more widely. An example is the PhD thesis of Charlotta Isaksson "Sustainable learning about indoor heating? – Domesticating energy technology in passive houses" (Isaksson 2009), which has a sociological approach. She is interested in understanding how the tenants experience and learn to live with energy related technology as a part of their everyday practises. In this thesis the residents are both asked about their experiences and opinions, but the indoor environment is also measured. The qualitative and quantitative results are analysed in a comparative study. It is therefore again necessary to use two set of "glasses" – the empirical analytical and the phenomenological.

A further discussion about the need of both scientific positions can be found in *Understanding of Danish Passive Houses based on Pilot Project the Comfort Houses*, in Jensen, O. B. (ed.) (2010) *Design Research Epistemologies I – Research in Architectural Design*. Brunsgaard, C. (2010), Aalborg: Department of Architecture, Design and Media Technology, pp. 61-78, ISSN: 1603-6204.

Part I

Part I will first present the eight cases that has been part of this research, then the result of study fields with a minor focus will be presented in an overall level.

Further reading about the results can be found in the following publications:

Komfort Husene – Erfaring, viden og Inspiration (2010) 1.ed. Isover-inhouse, Saint-Gobain Isover a/s, Denmark (The book can be ordered at www.komforthusene.dk)

The Architectural and Technical Consequences of Different Window Details in a Danish Passive House, Brunsgaard, C. et al. (2008), I Conference Proceedings: 12th International Conference on Passive Houses 2008, Passive House Institute, Darmstadt, Germany pp 375-380. (Appendix A)

3 Presentation of the cases

In the following the eight certified Comfort Houses will briefly be presented. The focus will be on the overall visual aspects. More knowledge about e.g. the technical installations or the construction details can be found in the book *Komfort Husene – Erfaring, viden og Inspiration* (Komforthusene 2010) a book about the Comfort Houses – a book that was made to communicate the knowledge about the Comfort Houses and the passive house concept to the Danish building industry.

Visual characteristics of a passive house are usually:

- a compact building shape
- the majority of the windows are orientated to the south to make use of the passive solar heat gains in the heating season
- has solar shading to protect the house from overheating in the summer period
- good insulated constructions

and most of the Comfort Houses has these characteristic (Komfort Husene 2010).

Figure 8. The eight certified Comfort houses – the cases.

3.1 Stenagervænget 12

The house is designed by the architect firm Møller Nielsens Tegnestue, the engineering firm Ellehauge & Kildemoes and the contractor Thyholm Murer A/S.

The house is constructed as a rectangular house and has almost 50% of the glass area orientated to the south. The house is a brick house with at cavity wall. The house has a saddle roof with asphalt roofing. The roof continues beyond the wall and creates an overhang of the walls and windows.

Figure 9: The house has a typlogy of a traditional Danish brick house – a house that can fit into most single-family housing area in Demark and fulfil most district plans.

Figure 10: The house is thought minimalistic. The walking lines in the house are reduced by creating a center in the middle by kitchen and living room in an open plan and the bedrooms are placed around it.

3.2. Stenagervænget 28

The architect of the design team was Jordan + Steenberg, the engineer was Cenergia Energy Consultant A/A and the contractor was Lunderskov Nybyg A/S.

The house is constructed like many other standard houses. The inner wall is constructed of areated concrete and the outer wall is brick. It is a brick roof, which is tilted to one side. This solution allows bigger windows area to the south that can contribute to the heating of the house and it increases the daylight conditions. Additionally, it gives the house a more modern look. The carport is created by a wooden construction that also shades for some of the southern windows.

Figure 11: The house is planed as a standard house and can fit into many traditional single-family housing areas.

Figure 12: The house has a simple floor plan that priorities to have a little niche even though it result in a less compact shape, which result in larger heat loss. The design team the has to compensate another place in the building.

3.3 Stenagervænget 37

The house is design by Aarhus Architects, Tri-Consult engineers, carpenter Michael Vogt Aps and the project leader was Kuben Byg A/S.

The house is constructed of lightweight prefabricated wall elements, which outside is plaster on insulation and inside gypsum boards. The roof is flat asphalt roofing. The carport is articulated by the overhang of the house as one shape swinging around the house creating shade for parts of the windows.

Figure 13: A minimalistic house with three main elements – the compact building shape, the solar shading and the concrete inner core with technical installations and bathrooms.

Figure 14: The floor plan shows the three main elements. The concrete inner core stands as a furniture, which contains the installations of the house and creates the focal point of the house separating the "private" and "public" rooms.

3.4 Stenagervænget 39

The house is designed by the architect firm Bjerg Arkitekter A/S, the engineers Erasmus & Partners A/S og finally the contractor Hassing-Huset.

The house is constructed by prefabricated wooden wall elements. The outer finish is black painted lists and inside it is either painted gypsum board or laminated birch. The roof is mostly flat except for the tilted part in the living room which allows a lot of daylight to come deep into the room.

Figure 15: A black lightweight wooden house with dynamic wooden shutters. Besides that, the house has a characteristic pergola which also creates shadow inside and outside the building.

Figure 16: The house has a central family room which has a tall floor-to-ceiling height that creates a good daylight. From the living room there are access to the bedrooms, bathrooms and kitchen.

3.5 Stenagervænget 43

The design team consists of Aart A/S architect firm, Rambøll Denmark as engineers and DTE-BYG A/S as contractor.

The house is build of prefabricated box elements in massive wood. The boxes are put together on site and finalised with covering. Outside the facade is covered with wood, where the inside is painted gypsum boards. The roof is a kind of saddle roof with asphalt roofing.

Figure 17: The house has two stories, which gives the second floor a great view of the area. The house is angled, which gives the house a more dynamic expression.

Figure 18: The two floors create an adult part and a children's section. Ground floor has a direct access to the outdoor area from the common room, where the first floor has a balcony towards the west. The garage is build together with the house which makes the house seem less compact than it is.

3.6 Stenagervænget 45

The design team behind this project is Ravn Architecture, Hundsbæk & Henriksen A/S engineers and Kurt Kirkegaard A/S as the contractor.

The design team wanted to show that it is possible to design a passive house in concrete, because when the project started the general expectation in the building industry was that passive houses is lightweight houses often in wood. Therefore this project has cavity walls in concrete. The house has two roof surfaces orientated in opposite directions.

Figure 19: The walls and roof continues out in the outdoor area to the south where it shades the windows and creates private spaces. Additionally, some of the windows are shaded by a pergola.

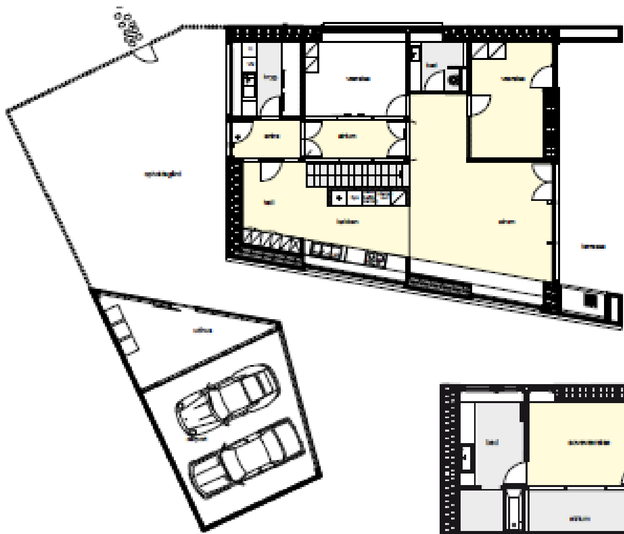


Figure 20: One of the characteristics of the house is the atrium in the middle of the house, which allows a lot of daylight in the middle of the house and into the bedrooms.

3.7 Stenagervænget 47 and Stenagervænget 49

+M was the architects, Esbensens Rådgiv. ingeniører A/S was the engineers and Villa Vision was the contractor in this consortium. They have designed the next two projects, because one consortium backed out of the project. The existing consortiums got the opportunity to design and build a house more, which ended up being this consortium.

Stenagervænget 49 is a squared two floor house with flat roof, see

Figure 21. It is a lightweight wooden frame construction with outer facade in plaster on insulation. The inside finish is painted gypsum boards. The house has a balcony on the second floor with a great view. To make a balcony like this result in more critical point according to air tightness and cold bridges than if not making the balcony. The house is planed to have a pergola in front of the four windows in ground floor to shade the windows in during the summer period. The plants should de deciduous and result in more solar heat gains in the winter period.

Figure 21: Stenagervænget 49 – called the "white" house. A minimalistic compact house.

The design of the second house – Stenagervænget 47 was based on the same building shape and floor plan as Stenagervænget 49, but the consortium wanted to try some different solutions, see Figure 21 and Figure 23. Therefore they chose to construct the house in concrete inner walls and brick outer walls. And they also removed the balcony and made a two story room in the living area. The house has no solar shading.

Figure 22: Stenagervænget 47 – called the "black" house. Like the white house this is also a minimalistic compact house. The black house has a two story open room. The space is articulated by a black brick wall central in the house.

Figure 23: The two floor plans show the similarities of the floor plans. Regarding the layout of the rooms is it mostly the balcony in the “white” house that is change to a two story space in the “black” house. Other changes are a larger percentages of window area in the “black” house, but the window area to the south is a little smaller.

4 The Construction Process

4.1 Introduction and Aim

The study of the design process has been a minor part of the overall research work, but the time spend on the construction site has been priorities to a curtain level, because the knowledge has given an exceptional insight to how the building industry perform in practise. It has been important for the holistic understanding of passive houses and the building industry in general. Additionally, the knowledge form this study has been used in the book about the Comfort Houses: *Komfort Husene – Erfaring, viden og Inspiration* (2010) 1.ed. Isover-inhouse, Saint-Gobain Isover a/s, Denmark and a DVD bout the construction process, which is part of the communication and knowledge sharing of the project to the building industry. All material can be found on the website of the Comfort Houses (www.komforthusene.dk).

The aim of this study field was to document the construction process of the Comfort Houses to identify new challenges, possibilities and/or problems. This knowledge would clarify if there were any new challenges to be aware of when constructing future passive houses.

In the following some of the findings will be presented, where a thorough review can be found in the book *Komfort Husene – Erfaring, viden og Inspiration* (Komforthusene 2010) and on the DVD (www.komforthusene.dk).

4.2 Results

The interviews with the craftsmen have mainly resulted in knowledge about very specific issues in the construction process and only a few more general experiences. The informal interviews from the construction site, the observations and the photo documentation have contributed to the following.

Generally the consortiums and the craftsmen think the work is not so different from what they are used to construct. E.g. the brick layers think their work is more or less the same, the space between the walls is just bigger. The foundation is just a little higher because the insulation layer in the ground is thicker. A contractor thinks the construction flow was the same; they only had a bigger focus on the management of construction site (Brunsgaard 2009b). The part that has been the biggest challenges was the mounting of windows, both regarding the actual mounting in the wall without creating too big cold bridges, but also according to handling the heavy windows and the proofing between the vapour barrier on the window and the wall. Specific examples will be presented in the following:

4.2.1 Mounting of windows – fixing, air tightness and cold bridges

Stenagervænget 39: The craftsmen experienced that it was easier to mount the vapour barrier on the windows before mounting them into the wall and then connect the vapour barrier with the vapour barrier in the wall (light weight house). Usually they mount the vapour barrier on the window after it is mounted into the wall.

Stenagervænget 49: The vapour barrier which was fixed to the window was not wide enough, so they had to take the vapour barrier from the wall and bend it into the embrasure of the window. It would be easier if they could meet in the corner in stead.

Stenagervænget 37: They wanted to minimise the cold bridge around the windows and therefore installed an extra layer of insulation (1-1½ cm) to the element before the inner finish of gypsum boards was installed. To be able to attach the gypsum boards they needed to break through the insulation and install small pieces of gypsum board (Figure 24). The carpenter was not so pleased with this solution because it took a lot of time.

Stenagervænget 28 and 43: Two houses have used an unusual material called polyurethane when mounting the windows in the wall. The material insulates twice as well as wood and it is possible to screw into it, which gives more possibilities than normal insulation. This material both minimises the cold bridge and it is an easy way to mount the window. First a box is built in polyurethane boards and then the window is mounted into that. After that the box is mounted in the wall. By using this solution it is not possible to put windows in the house in one day as they normally do, because it takes more time. The reason is a combination of the mounting method and the fact that the windows are much heavier than normal windows – they need to be more people than usual (Figure 25).

Stenagervænget 37: One consortium did not know how to make the casing of the window before the actual window was delivered, because they did not know how the window looked like before that.

Stenagervænget 12: The challenge in a brick house is to mount the windows between the inner and outer wall, which is the best place according to the linear thermal transmittance. The consortium solved it by supporting the windows underneath by an angle fitting on the inside of the outer wall, and by a straight fitting on the sides of the window to the inner wall to stabilise (Figure 26). The craftsmen think this solution takes more time than a normal mounting of windows.

Several houses: The windows have to be lifted into the windowsill with a crane, because the windows are heavier than regular windows. It is because of the three layers of glass and because some have in the design gathered the windows into bigger elements to make minor cold bridges in the joints and in the frame area.

Figure 24: The picture shows an example of the detailing around the windows. To be able to attach the final gypsum board you need to make holes in the insulation and install pieces of gypsum to have something to mount into – a solution that take a lot of time to complete, Stenagervænget 37.

Figure 25: The picture shows the windows mounted in a polyurethane box, Stenagervænget 28.

Figure 26. The pictures show an example of how to mount a window in a passive brick house in the insulation layer, Stenagervænget 12.

Even though the biggest challenges were regarding the mounting of the windows, some other interesting issues come up. In the following some of those are exemplified.

4.2.2 Ground deck

Stenagervænget 28: A new challenge when insulating the ground deck was to use much more insulation and considering how to combine the layers of insulation. In some cases the ventilation pipes is placed in the insulation layer and therefore they needs to install them before the deck was casted. One solution is to have a top layer of 75 cm where the pipes fit into, but then the insulation will not be supported by the inner foundation block when casting (Figure 27 and Figure 28). Therefore they have to glue the insulation on to each other – a more time consuming process. Additionally they had to cut the insulation according to the pipes.

4.2.3 Vapour barrier in the wall

Stenagervænget 37: The vapour barrier was already put into the prefabricated wall element and the challenge was to combine the vapour barrier between two elements. The solution was to bend the vapour barrier around the corner and then place a joint in black butyl filler and jam the elements together (Figure 29). They were excited to see what the blower door test would show - luckily it went well.

Stenagervænget 12 and 39: When mounting the vapour barrier they are more careful and meticulous than they are used to, because of the strict demand to the air tightness. In the connections they both made an overlay, used joint filler and tape at the same time. Besides that they taped all the staplings to secure the air tightness. In that process they found that not all type of tape was suitable. They experienced that some of the tapes was not sticky enough; therefore they discovered the importance of using a good quality tape. They also discovered that they could see if the tape was letting go of the vapour barrier if the tape was transparent, then they could easy double-check if the work was done well.

4.2.4 Painting the wall

Stenagervænget 37: The frame of the windows is insulated from the outside by façade insulation. Then the painters have to use tape to prevent the paint to get on to the window frames. Normally they have a joint with filler between the insulation and the window and do not have to use the tape. This means they used more time in this case than normally.

4.2.5 Prefabricated concrete walls

Stenagervænget 45: The mounting of a cavity wall in big concrete slabs had challenges according to getting the walls in plumb, because they had developed new wall tires in carbon fibres and the possibilities for adjusting their position back and fort was too little (Figure 30). Besides that, they had problems with insulating the cavity as it was difficult to put the thick pieces of insulation down between the big plates of concrete given by the friction between the wall and the insulation. At the same time it was difficult to get the insulation evenly spread out without leaving any holes, which would create unwanted cold bridges. This procedure was very time consuming and expensive because a crane was active the whole day. Maybe some of the problem could have been solved if they had blown the insulation into the construction instead.

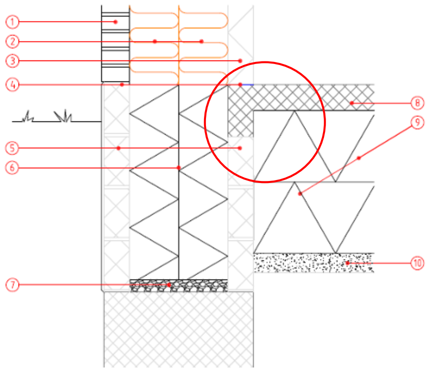


Figure 27. The figure shows the principal of the foundation and the ground deck. The actual thickness of the insulation layers is not displaced. The layers were 175mm + 100mm + 75mm from the bottom, Stenagervænget 28.

Figure 28: The picture show the casting of the deck and how it will be connected to the inner block of the foundation. It also shows the ventilation pipes in the top layer of the insulation, Stenagervænget 28.

Figure 29: The picture shows the mounting of the prefabricated wall element. The vapour barrier is already installed in the element. The air tightness is secured by at joint in black butyl filler between two wall elements were the vapour barriers meet, Stenagervænget 37

Figure 30. The illustration shows the mounting of an outer concrete wall to an inner concrete wall with wall tiers in fibre material. The craftsmen had difficulties with getting the wall in plumb, because the adjustment of the wall tiers was not flexible enough, Stenagervænget 45.

Other aspects that several of the consortiums mention are the importance of the communication from the design team to the craftsmen about the detailing of the house (Brunsgaard 2009b). It is important for them to know how and what they have to do and why they have to do it that way. In one occasion, where the foundation was designed with Foamglass (www.foamglas.dk) under the inner wall to reduce cold bridge, the craftsmen was about to use regular foundation blocks instead of Foamglass. Fortunately the engineer came by and discovered what they were about to do and stopped them (Brunsgaard 2009b). If the design team had communicated to the construction team why it was important to use Foamglass instead of normal foundation, this might not have happened. Another problem in this case is that the contractor did not want to have construction meetings during the construction process, which he was allowed to refuse because it was a turnkey contract. In the next project with passive or low energy houses, the engineer will not have that kind of contract; he thinks the construction meetings are very important in this kind of projects (Brunsgaard 2009b).

A consortium recommends that the solutions have to be designed simple and not too complicated, so the craftsmen can imagine the solution by them self. He also recommends that the solutions have to be carefully thought through. It is possible to draw almost every thing, but maybe it is not posible to build (Brunsgaard 2009b).

4.3 Conclusion

This study shows that many of the solutions of a passive house are more and less the same as constructing a house fulfilling the conventional level of performance. The biggest different is that it is important to be more careful and profound in the work because of the air tightness and the cold bridges. The part that have been the biggest challenges was the mounting of windows, both according to the actual mounting in the wall, but also according to handling the heavy windows and the proofing between the vapour barrier on the window and the wall. The general perception is that they have spent more time than they are used to in the detailing. If it is because it is the first time they construct passive houses or if it is because it is necessary when constructing in a passive house, this study cannot directly tell. But a development of new products and mounting method that will optimise the consumption of time in the construction process will be beneficial for the building industry in the future.

5 Architectural Expressions of Passive Houses

5.1 Introduction

The experience with the development of the Comfort Houses has showed which typical principals that affect the expression of a passive house. The solutions in the Comfort House have to some extend influence the traditional way of designing a single-family houses and the Danish architecture. The building technological areas of passive houses can also influence the architectural expression. The following will shortly clarify important aspect to be aware of according to the architectural expression and the building technology when designing passive houses.

5.2 Basic Principal of Passive Houses

There are many myths about passive and low energy houses according to their architectural appearance. Examples could be: *"Passive Houses are boring houses with small windows"* and *"It is '70ies houses with gun slits"* etc. The examples in the Comfort House project show that it does not need to be that way in a Danish context (www.komforthusene.dk and Komfort Husene 2010). But do the concept and building technology not have any effect on the architectural expression?

Well, if you look carefully you can see that the Comfort houses are passive houses. Both the basic principal of the passive house concept and building technology has an influence on the expression and design-concept. The basic principle of the concept has the most importance like compact shape, orientation of the largest window areas to the south and the limited area to the north, well insulated envelope and in most cases solar shading. All consortiums have worked with these basic principles more and less articulated in the design of the house.

How these aspects are expressed in the houses will be exemplified in the following. Generally in new construction and existing buildings the window is designed to add light and air to the dwelling and create a contact to the outdoor areas. In a passive house, windows gets an extra dimension, namely to add the dwelling passive heating in winter through the windows without losing too much heat. Therefore, the orientation of the windows is an important parameter and often results in a larger window area to the south. Some of the houses place for example the bathroom in the northern part of the house and leave out the windows to reduce heat loss and maybe instead placed more windows in the south. A design decision like that has influence on the distribution of the spaces and thereby affects the main concept of the house, see Figure 31. The houses are relatively compact and some will probably claim that compactness makes the architecture monotonous and boring, but not necessary. By looking at the cases of the Comfort Houses, some worked with other initiatives to break the compactness. E.g. a simple square house is loosened up by solar shading in an organic shapes and an asymmetrical element in the interior. Then the house is experienced more exciting, see Figure 32. Other houses have worked with elements as an extension of the building envelope e.g. covered terrace or joining the housing unit with the garage in one shape, see Figure 33. Some houses also choose to break the compact shape with small niches in the facade or roof despite a lager surface area, but they still manage to keep within the passive house requirements.

Good insulated constructions means more insulation in walls, ceilings and floors and the impact on the architectural expression vary according to which part. Eg. the insulation of floors and ceilings have not had such a big impact on the expression, because the extra thickness is "hidden way" in the design. The ground deck ends is in the same level as in a usual house, but starts further down in the ground to make room for the extra insulation. The same principle goes for the roof. It does not show directly that the house will be a little higher than normal, since the total thickness of the ceiling not will be exposed unless the roof has a skylight. The walls on the other hand have a greater impact on the architectural expression, because the doors and windows break the wall and expose the wall thickness. Several consortia took this as a challenge and searched for opportunities and develop fine solutions. Some has for example located the windows in such a height that children can use the embrasure as a sitting area, see Figure 35. Others have merged windows to larger part and let them go to the floor. That way the embrasure in the bottom becomes a part of the floor area and the "holes" in outer wall is considerably minimized, see example in Figure 34.

The materials of the wall also have an influence on how the house expresses itself and what texture the house will get. Some of the Comfort houses have chosen other materials than what is traditionally seen in other single-family neighbourhoods. Maybe it shows that passive houses bring new and different materials into the construction of single-family houses even though the projects were selected by a jury, who wanted to show diversity in the project. More lightweight houses are e.g. seen in the project and some of them have plastered facades, which until now has been limited widespread in Denmark. In some cases the reason for choosing different materials was to minimise the wall thickness because the outer wall has no static function, but simply adds additional thickness to the wall (Brunsgaard 2009b). This shows how more practical choices can determine textural expression of the house.

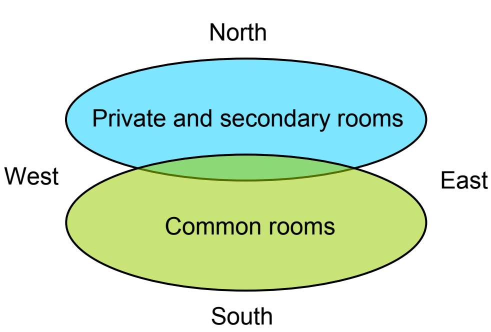


Figure 31: The diagram show a conceptual drawing of how the functions in a passive house usually are placed according to each other. The private and secondary rooms are place to the north without windows or just minimized or placed in the western or eastern façade to minimise the heat loss. This affects the main concept of the house.

Figure 32: The compact square shape of the house is loosened up by the organic shape of the solar shading and the asymmetrical element in the interior. The house is experienced more exciting than a square house.

Figure 33: The compact shape of the building envelope is disguised by an extension of the building envelope joining the housing unit with the garage in one shape.

Figure 34: By merging the windows into larger part and let them go to the floor, the embrasure becomes in the bottom a part of the floor area and the "holes" in outer wall is considerably minimised.

Figure 35: The deep embrasures in a passive house are in some houses design to be used as a sitting area by lowering the window sill.

5.3 Building technology and architectural expression

The building technology will to some extent also affect the architectural expression, but not so much as the basic principal of a passive house like described in previous section. The architectural expression is influence by the building technology because other principles like: minimising cold bridges and achieving air tight constructions. Generally the aim is to make “cold brigde free” solutions in passive houses (Feist et al 2007). It is important both according to minimising heat loss, but also to avoid areas with discomfort. At the same time it is important to avoid condensation which can grow mould over time. It is mainly the thermal bridge issues around the windows, which affect the architectural expression, again because the details around the roof and foundation are more hidden.

Placement of the window in the wall can be solved in several ways. E.g. close to the outer wall or in the middle or in the back close to the inner wall. It gives different expressions to the house, but also different values of the linear thermal transmittance, which can effect the energy calculation. A desk study of this problem was presented at the 12th International Passive House Conference in Nurnberg in the paper *The Architectural and Technical Consequences of Different Window Details in a Danish Passive House*, Brunsgaard, C. et al. (2008), I Conference Proceedings: 12th International Conference on Passive Houses 2008, Passive House Institute, Darmstadt, Germany (Appendix A). The three variations are showed in Figure 36. The study investigated a traditional Danish brick house with cavity wall. Besides discussion where to place the window the work also considers the mounting of the window and the finish in the embrasure, which also are important to take into account. Later sensitivity analysis shows that the shadow from the wall on the window also has a big impact at the final space heat demand. Those results are presented in the book about the Comfort Houses (Komfort Husene 2010). The Comfort Houses as a whole present various solutions because of the different materials of the main construction. There are for instance seen examples of minimising of cold bridge by isolating the frame from the outside by façade insulation with plaster, see Figure 37. It means that the expression of the frame from the outside seem more narrow. More common solutions known from “normal” single family houses are also used in the project, however they create lager thermal bridges. But one can compensate other places in the house, by for example using more insulation in the attic or install a better ventilation system. It is also possible to mount the window by using fittings to place the windows in the middle of the insulation, which forms the basis for the smallest thermal bridge. In this solution it is important to think of how to solve the embrasure both exterior and interior, in relation to get the right expression that fulfils the architectural and functional requirements to the project. In this process it is of course also important to consider the air tight layer and how to cover this. Some time the airtight layer is not the same type of material throughout the building, therefore the transitions must also be considered, e.g. how is the vapour barrier attached to the masonry and to the window and how is it covered and finished afterwards? An example can be seen in Figure 38.

Figure 36: The three examples show tree different way to place the window in the wall. The solutions have different linear thermal transmittance in the connection between the wall and the window, but they also have different architectural expression - both aspects have to be taken into account when designing the house.

Figure 37: Here the window frame is insulated from the outside to minimise the cold bridge.

Figure 38: The pictures show a solution to cover the connection between the air tight layers and the window and the masonry and the PE vapour barrier. It is covered with a casing and finished with a list. This solution becomes a characteristic detail to the interior expression of the house.

5.4 Discussion and Conclusion

It is stated that the basic passive house principles has greater impact on the architectural expression than the building technology, maybe with the exception of the detailing of the windows which has more aspects to consider. How much impact they actually have on the architectural expression, might be a lot for the trained viewer, but a viewer with no or little knowledge about passive house principles might not immediately see that the house is different from a "normal" single-family house. If some thinks the Comfort Houses look different, it can be because the design of the house is influenced by an architect who has other ideas than traditional housing. Only a small amount of the houses in an ordinary single-family neighbourhood is designed by architects in Denmark, most houses are standard housing (catalogue houses). Despite that, what do we think about the change of the architectural expression because of the passive house concept? Is it allright to show the passive idea with the house discreetly regarding optimized building envelope and passive solar heating? Or is it intended that we must preserve the architectural expression, we know from the existing single-family houses? It is believed that as long as the architecture meets the basic principles of architectural aesthetics and functionality it is very natural for architectural directions to change over time and now it is maybe the time for changes. Nevertheless, the houses are designed with at foundation in the Danish architectural tradition and idiom. Therefore it is expected that they fulfil the needs of the Danish house buyers.

The evaluation of the different consequences of the passive house concept and building technology on the architectural expression, demonstrate that it is important that solutions are integrated into the main architectural concept to create a holistic solution. Most of the aspect of the passive house affects not just one, but several other aspects simultaneously, therefore it is important to see opportunities in the challenges to develop good solutions. The solutions are often not so far from what we already know. It is believed that a creative design team can easily integrate both the construction and engineering principles and the principal of a passive house in aesthetically well-functioning architecture. The design team just needs to be aware of what they are doing and know the impacts form the aspects of energy on the architecture.

Part II

Part II covers the central part of the thesis. Each chapter introduces the scope and findings of the three study fields in focus: *The Design Process*, *Architecture and Everyday Life* and *Indoor Environment*. The three topics answer the three sub-research questions:

- *How has the consortiums behind the Comfort Houses approached the design process according to teamwork, method and tools? And what barriers and possibilities lie within the approaches?*
- *How do the occupants of the Comfort Houses experience the passive house architecture and the technical service systems? And has their everyday life changed by moving into a passive house? If so, how?*
- *To what extent do the Comfort Houses live up to a comfortable indoor environment? And how do the occupants of the Comfort Houses experience the indoor environment and the adjustment of it?*

Part II finishes with a correlation of the findings in a comparative study across study fields, a discussion and conclusion, which tries to answers the overall research question:

What can the experience from the Comfort Houses enlighten about the future production and use of Danish passive houses?

Further readings about the research presented in the following can be found in:

The Critical Design Process – Experiences from the first "Comfort Houses" in Denmark. Brunsgaard, C. et al. (2010b). I: Architectural and Planning Research. 16 s. (Appendix A)

Occupant Experience of the Everyday life in some of the first Passive Houses in Denmark. Brunsgaard, C. et al. (2010c). I : Housing, Theory and Society. 25 s. (Appendix A)

Evaluation of the Indoor Environment in the Comfort Houses - Qualitative and Quantitative Approaches. Brunsgaard, C. et al. (2010d). I: Indoor and Built Environment. 23 s. (Appendix A)

6 The Critical Design Process

6.1 Introduction and aim

The attempt to understand the process of design within architecture has been interesting in research for many years. Hillier, Musgrove and O´Sullivan write a paper in 1972 (Hillier et al. 1972) and discuss the approach to design based on other research done fifteen years before that in UK. Later people like Donald Schön (Schön 1983) and Bryan Lawson (Lawson 2002) also enters this field of research. All have delivered knowledge which is still current in the discussions today. Some courses of explanation why design processes are so interesting can be explained by a better understanding and optimisation of the process can improve the design and you can save time and resources. Additionally, it maybe result in a better experience for all participants. Therefore the objectives of this study field was to clarify the different design processes in the comfort houses based on interviews with the consortiums responsible for the design of seven of the houses.

The following chapter contains the main findings of the research question:

How has the consortiums behind the Comfort Houses approached the design process according to teamwork, method and tools? And what barriers and possibilities lie within the approaches?

The full description of the findings can be found in the article *The Critical Design Process – Experiences from the first "Comfort Houses" in Denmark*. Brunsgaard, C. et al. (2010b). I: Architectural and Planning Research (Appendix A).

6.2 Different methodical approaches to design processes

The knowledge from the interviews about the practical experience is compared with different approaches of Integrated Design Processes (IDP) and the "Traditional Design Process" (TDP) to illustrate what kind of processes the consortiums have had when designing Comfort Houses. In the following different approaches to design processes are presented.

6.2.1 General introduction to design processes

Design processes are not easy to define, because the design problems are often ill-defined and wicked. No design problem will ever be the same; therefore each design situation is unique. Additionally, they often have great complexity e.g.:

"Enlarging our windows may well let in more light and give a better view but this will also result in more heat loss and may create greater problems of privacy. It is the

very interconnectedness of all these factors which is the essence of design problems, rather than the isolated factors themselves." (Lawson 2002, p. 58-59)

This complexity affects how to approach the design process. Many writers have tried to map the design process in identifiable activities in a logical order, but those attempts turn out to be rather rushed. Lawson suggest instead a "map" of a design process, though without a beginning or end, which illustrate how design processes often have very little direction, because all issues inform each other, see Figure 2. The designer need to go back several times to identify another problem and establish another solution and visa versa (Lawson 2002). This is what Donald Schön would call *"reflection-in-action"* or *"having a conversation with the drawing"*. He talks about a spiral process which leads from understanding to action (attempting a solution) and to new understandings. The designer understands the unique and uncertain situation through the attempt to change it, while at the same time change it, to be able to understand it (Schön 1983).

Theoretically there are several solutions possible, but only one of these will be the final solution and reductions have to take place. Hillier, Musgrove and O´Sullivan reject an Analysis/Synthesis approach and agues for conjecture in design development:

"We have to recognise, therefore, that before the problem is further specified by the gathering of data about the problem, it is already powerfully constructed by two sets of limiting factors: the external constrains(…) and the designer's cognitive capability in the relation to that type of problem. It is quite likely that these latent limitations are already being explored right from the beginning, if the designer is conjecturing possible solutions, or at least approximations of solutions, in order to structure his understanding of the problem, and to test out its resistances. There is also a very practical reason why conjecture of approximate solutions should come early on." (Hillier et al 1972 p. 29-3-9).

The design process is a cognitive process and the designer conjecture an approximately solution to structure the understanding of the problem and tested its resistance. They therefore state that design proceed by Conjecture/Analysis (C/A) rather than Analysis/Synthesis (A/S) (Hillier et al 1972), the terminology which Maureen Trebilcock also used in her research. She has made studies of the design processes behind eight sustainable buildings in Europe and South America (Trebilcock 2009). She explains (based on work by Hillier, Musgrove and O´Sullivan) that there are researchers who believe the model of integrating environment sustainability in architecture is based on an understanding of the design process as A/S; where the problem is broken down and analysed in sub-problems and individual problems, after that reaching individual solutions and sub-solutions until achieving the overall solution. Maureen Trebilcock proposes that the Integrated Design Process (IDP) in practice is closer to a C/A model that suggests that designers would propose an idea that is holistic in nature before attempting to do any analysis. She further describes that these terms describes the difference between research and practice and also the difference between the architectural (C/A) and engineering (A/S) approach and explain the conflict in combining these two paradigms in an IDP like the one developed by IEA Task 23 (Löhnert 2003). She concludes among others that it is necessary to have a C/A perspective to IDP, because she thinks it is *"…unlikely that integration could be achieved by analysing enormous amount of information, synthesising and evaluating it until finding the optimal solution, …".* And conclude that the education of architects and engineers has to cover a basic knowledge and skill of the other profession (Trebilcock 2009).

6.2.2 The traditional design process

Often, if generalised, the design processes in practise, which could be called the traditional design process (TDP) proceeds like this: The architect and the client agree on the design concept consisting of the form concept, orientation, fenestration and the exterior appearance like characteristics and materials. Then the engineers and consultants are asked to implement or design technical systems for the building. This procedure is quite simple mainly because the “active” actors in the process at the same time are limited and they are implemented linearly (Muir et al 1995 and Löhnert 2003), see also Figure 39 (TDP). In a linear process it is often difficult or even impossible to optimize the design according to e.g. energy and indoor environment, because the expertise comes in late in the process. This is a problem especially when designing low energy houses where even more parameters are important to consider than in standard building design fulfilling the conventional level of performance (Löhnert 2003). As described above the architect has a more cognitive approach and highly use *reflection-in-action* and switch between problem and solution, where the engineer more is a *“problem-solver”* who has a scientific and analytical approach to find solutions. Therefore it is stated that TDP have the “layout” illustrated in Figure 39 because the different professions have different ways of approaching the design and “split the process between them”.

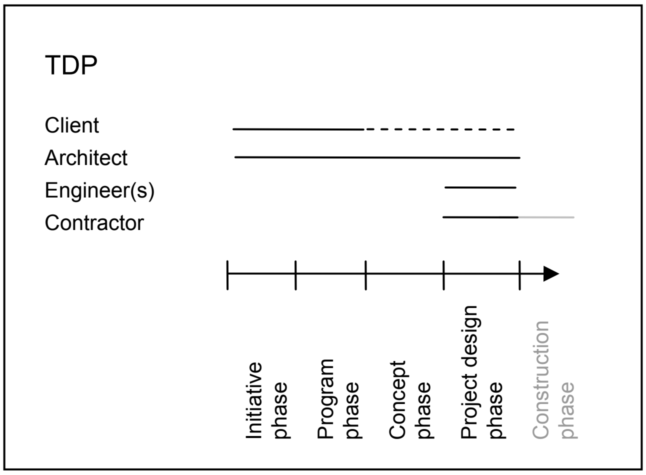


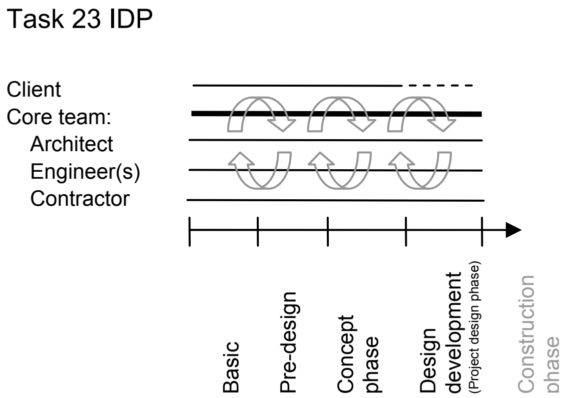
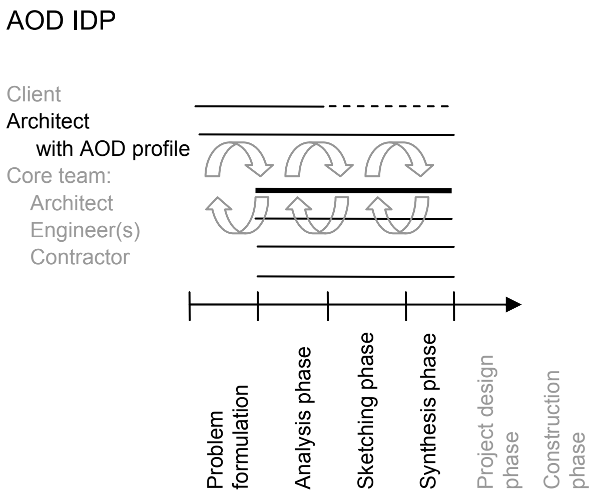
Figure 39: The TDP illustrated by the different phases and the different actors involved.

The design processes have become even more complex today because the low energy goal also affect the architectural design of the building – today the goals cannot be reached just by technology. Therefore the architect either needs more knowledge or need to bring in expertise on another design stage than they are used to, to reach the goals. To deal with higher level of complexity some suggest the IDP approach. But there exists different understandings of that.

6.2.3 Different integrated design process (IDP)

In the last years a number of different approaches to IDP have been developed and some with a slightly different naming like: Integrative Design Guide to green building by Bill Reed (Reed 2009) Integrated Energy Design by Esbensens Consulting Engineers (www.esbensen.dk). Generally most of them wish to fulfil the same goal. They generally focus on the importance of integration of both engineering and architectural design aspects in a holistic synthesis. The most acknowledged approaches to IDP include an iterative process, where all design aspects are discussed by all actors in the team – like method from IEA Task 23 (Löhnert 2003) or the Integrated Design process developed and used at Aalborg University in the education Architecture & Design (Knudstrup 2004, Knudstrup 2007), which will be the IDP approaches referred to in this work. Table 6 explain these two IDP approaches. To further illustrate the different content and focuses of the methods conceptual diagrams are developed. They illustrates how the development of the processes regarding integration of both technical and architectural aspects proceeds, see Figure 40. Technical means in this case energy and indoor environmental issues. The diagrams show that the IDP approaches vary according to the TDP. Further readings about the different IDP approaches can be found in the article *The Critical Design Process – Experiences from the first “Comfort Houses” in Denmark*. Brunsgaard, C. et al. (2010b). I: Architectural and Planning Research (Appendix A) or in the technical report *Strengths and Weaknesses of Different Approaches of IDP* (Brunsgaard, C 2009b).

Table 6: Examples of different Integrated Design Processes.

International Energy Agency (IEA) Task 23 (Task 23 IDP): Optimization of Solar Energy Use in Large Buildings, subtask B (Task 23 IDP). In this approach the client takes a more active role than usual, the architect is a team leader instead of a sole form-giver and the different engineers, including an energy specialist, takes an active part in the early stages of the process. The process is based on specialist knowledge of each actor. The design develops through iterative operations (Löhnert 2003).	
The Integrated Design Process, Architecture & Design, Aalborg University (AOD IDP). This approach is developed as a method for architecture students at Aalborg University and is developed from an architectural point of view. The work is based on the architects design process but includes consideration of some basic technical engineering parameters and application of tools from engineering in the beginning of the design process. All persons carry a new professional interdisciplinary profile that aims at integrating architectural skills and the necessary engineering skills and tools to fulfil the goals. The design develops through iterative operations (Knudstrup 2004, Knudstrup 2007).	

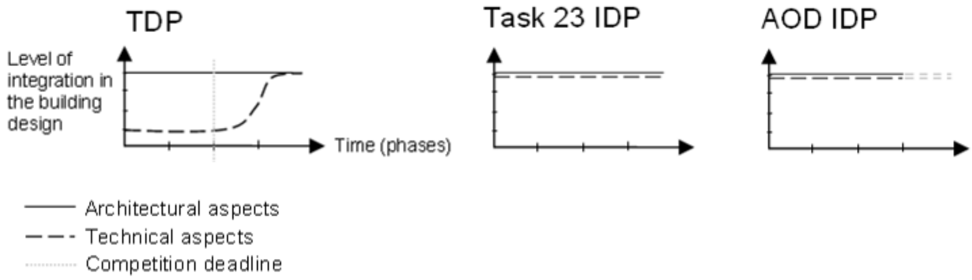


Figure 40: The conceptual diagrams show how the process develops according to the level of integration of the architectural and technical aspects in the different design methods.

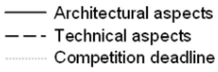
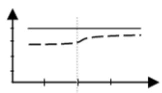
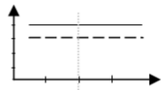
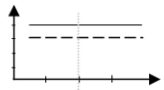
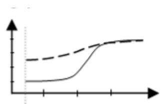
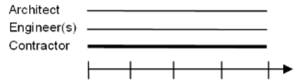
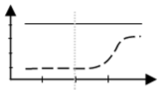
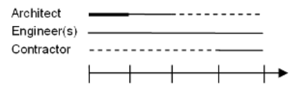
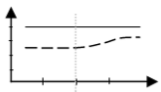
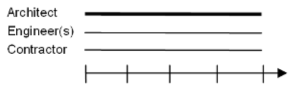
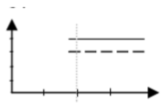
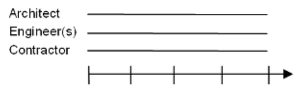
6.3 Results

In the following the main result of this study will be presented. Further readings about the results can be found in the article *The Critical Design Process – Experiences from the first "Comfort Houses" in Denmark*. Brunsgaard, C. et al. (2010b). I: Architectural and Planning Research (Appendix A). The results are presented in two sections. First the different design approaches is discussed and identified and later the tools applied in the design processes are presented. The results are presented by conceptual diagrams and quotes from the interview. Further details about the specific interview can be found in the technical report *Interview Report about the Design Processes behind the ´Comfort Houses´* in Danish (Brunsgaard 2009a) published internal at the Department of Civil Engineering at Aalborg University.

6.3.1 The different design processes in the Comfort Houses

The consortiums were not told to use a certain method in the design process and the interviews also showed that all consortiums have worked without a specific method or at least they have not been aware of it. To illustrate the different consortiums approaches to the process individually and compared to each other, their approach are placed in a matrix in Table 7 on the next page. The design approaches are illustrated in conceptual diagrams in the same way as done with IDP approaches in Figure 40. Additionally the matrix shows the level of experience the consortium have had before the project and a diagram showing when the different actors have been involved in the process. The matrix shows variations in the different approaches and that the majority of the consortiums have worked very different from the TDP and similar to the IDP, even though they were not introduced to any IDP method.

Table 7: The matrix shows a quantification of some of the result of the interview.

	Previous experience with low energy buildings (Much, some, limited)	Design approach 	Phases and the actors involved
C1	Limited		
C2	Much		
C3	Some		
C4	Limited		
C5	Limited		
C6	Much (Architect with interdisciplinary profile)		
C7	Much		

A comparison shows that there is a tendency that the consortiums with the most experience also are the consortiums with the most integrated design process. This might illustrate that the experienced consortiums have found out that they need an integrated approach (without defining it as such) in this type of projects and therefore took this approach. An example of the integrated approach is well illustrated in this quote by consortium 3:

"We did not think architecture and then think technique which should be stuffed into the architecture afterwards. Or architecture first and then we had to document if the energy calculation is fulfilled afterwards. We made some sketches and calculated, considered the technique, then we made changes, considered the technique again, calculated energy - and also considered how we practically should build (the house) … We continuously did that in steps, where we tried to keep all the things (parameters) in focus at the same time, instead of trying to fix it or bring it in at a time where it is hard to get it integrated." (The engineer, consortium 3)

Especially two cases do not fall into the integrated approaches. In consortium 4 the project had such binding constrains that the architect was not able, in her own opinion, to design good architecture within these, it resulted in architecture, but not as good as it could be. The process in case 5 had a little different characteristic. They explained that they had a different approach and closer teamwork than they were used to in a more traditional project – they had much closer collaboration from the beginning of the project. But as the interview moves forward the notion of close collaboration might not be so close after all. One engineer explains the process like this:

"We knew it should be a passive house, but he (the architect) was not so constrained by it in his first creative process because he was thinking of how he could design a super attractive building aimed for the modern family. And then we tried (the engineers) to drag it back and said: what should be done so it could become a low energy building? He was given free rein, free enough that he could try to make some first sketches. ... Of course we had given the architect basic knowledge by saying: 40% of the window area should we try to orientate to the south." (The engineer 1, consortium 5)

This design approach seems similar to a TDP, because the architect developed the architectural concept and later the expertise of the engineers come in and they *"drag the design proposal back"* as they say. Another engineer in the consortium supports this in a later section in the interview:

"I think is was a bit annoying that you in principal sketch a house, and there was not a long time available to do that, and win the competition, wupti! Then you have promised how it should look like, what building services it has and … the cost. Then you are extremely constrained, right? And that is before you have had the time to consider the design, because you have not had the time to calculate and you actually do not know very much (about passive houses). … What was it that we were about to do? We had to learn, but we could not use that for anything because we had promised (how it should look like) … we could have changed a little on the windows ... But we had promised how the house should look like and it is really the architectural idea how the window is placed ... then you cannot change that." (The engineer 2, consortium 5)

This engineer felt that she had too little influence on the architectural concept and her knowledge and expertise could not be implemented. This could be categorised as a C/A approach but the conjecture in this case was too weak, the first suggestion was not holistic enough in it nature, which made it difficult to fulfil the demands of passive houses according to the quotes above. This tells something about the communication and the teamwork in the consortium. If the engineer had been a more integrated part of the first ideas, the concept might have been more holistic.

The process of consortium 4 and 5 show how intensions of working close together in an integrated process can end up being very little integrated, some actors ended up being even frustrated about the process. It does not mean that the outcome of these processes is poor, but it says something about the path to the final result. By optimizing the process maybe the consortium could have saved resources – both personal and economical resources.

6.3.2 Tools applied for documentation and design development

In an IDP it is essential to use tools to document if the requirements are fulfilled but also to ensure that the design is moving in the right direction during the process. The typical tools the consortiums have used are shown in Table 8. The main difference in this project compared to a "normal" project, was that the projects had to be certified as passive houses and therefore the energy use had to be documented by PHPP, which was a new tool for most consortiums. Some used the tool very strategically by making consequence analysis, which especially was a success for the architect, because he got a common understanding of which design decisions had influence on the energy performance and how much. It strengthened the communication in the consortium.

Table 8: Typical tools the consortiums have used during the design process.

Architectural tool	Energy calculation tools	Indoor environmental tools
– AutoCAD – Hand sketches – Some 3D modelling in the sketching phase	– Be06 in the early stages of the sketching phase (Danish software for energy calculations) – PHPP in the detailing part or in the whole process (Passive House Planning Package (www.passivehaus.de))	– Static calculations of the risk of overheating in PHPP. – Other indoor parameters as daylight and noise are not documented by calculations. The solutions are instead chosen according to the experiences from other building.

According to documentation and analysis of the indoor environment, the tools the consortiums have used have been very limited. In most consortiums the thermal comfort according to overheating was calculated in PHPP, while indoor environmental aspects like daylight and acoustics in the majority of the cases were only discussed. The design solutions were then based on well known solutions or based on solutions that might accommodate a well known problem. Most consortiums know the tools, but they are not used to work with them especially not in single-family house designs. By not using the tools problems might arise as solutions selected are based on existing building cases. The existing building stock is constructed very differently than the Comfort Houses and therefore the consortiums can not be sure if it will react the same way. E.g. the walls are much thicker than in a standard house and can result in less daylight in the rooms and the orientation of the house and windows are much more fixed. The article *The Critical Design Process – Experiences from the first "Comfort Houses" in Denmark*. Brunsgaard, C. et al. (2010b). I: Architectural and Planning Research (Appendix A) gives different suggestion to why it has not been better documented.

6.4 Implementation of IDP

All consortiums state that the future design approach should be something different from the TDP. The result of the analysis seems to aim for a methodical approach in the IDP region of Task 23 IDP and AOD IDP, because all consortiums agree that all actors has to work together from the beginning of the design process and the design is a joint mission. Furthermore, the majority of the cases have approached the assignment with a more integrated approach than the TDP. The method of Task 23 IDP, is suitable because it is based on the actors' individual professional knowledge (they do not carry a interdisciplinary profile) and can be introduced in the existing practises today. Maybe not in its pure form, but adjusted to the individual project. The projects in the "Comfort Houses" had a C/A approach where the architect and engineer (and contractor) together developed a holistic design proposal which then is optimised and tested by tools, mostly PHPP in this case. This indicates that extensive analysis of e.g. low energy components is not necessary, as Task 23 to some extend describes.

The problems we face in the IDP based on this study are mainly within the communication and understanding of each others professions and the knowledge when and how to document the design. A solution, which could support that, could be to include a Design Facilitator (DF) which has the interdisciplinary competences. A DF should have a broad knowledge and understanding of the language of both architecture and engineering. And should be able to overview of the project and thereby discover unclear issues, which for example could be missing documentation of the indoor environment as seen in this study. To succeed it depends a lot on the DF´s qualifications in both architectural and technical aspects. He/she has to have a general understanding of both fields but still sufficiently deep to discover problems or unclear issues for the team members to be able to solve them. Further discussions about this can be found in the article about the design processes (Brunsgaard et. al 2010b).

Another thing that could strengthen the IDP besides a DF is change in education of both engineers and architects (Knudstrup 2010). Today most candidates are educated to work within the TDP. E.g. the engineers learn to be problem solvers, meaning they have to fit the technical aspect into an almost finish architectural design. They should instead learn to be sketchier with their first ideas like architects do with their first drawings – they should be introduced to a more C/A approach. Then as the design process develops the solutions are getting more refined. On the other hand is the education of architects too independent of the technical aspect. Especially the traditional education of Danish architects, they mostly work with an intuitive artistic approach. No doubt that the Danish traditionally educated architects design very aesthetical architecture and it is important we do not loose that, but it is important they also are introduced to technical aspect and learn to take them into account. That way the future designers, both architects and engineers can be prepared to changes in the design processes in practise.

The knowledge of the IDP methods in practise today is limited. This study shows that it is definitely not sufficient; none of the consortiums have used or pointed out any defined methods. The barrier of integrating IDP in praxis can be the fact that the architects protect their professional domain and the engineers do not want to intrude on the architectural domain. Another barrier might be that the professions are not trained to work in an integrated way. Besides that the building industry is not based on trust and openness to each other, which is important in an IDP. Additionally there are some problems by creating a consortium from an early design stage, because of the compulsory competitive tendering for the public sector. And finally there are different definitions of the IDP, which this article also shows in the theoretical section about design processes.

6.5 Conclusion

The study of the Comfort Houses has shown the width of how a design process of passive houses can be approached, but it has also showed that the IDP approach is beneficial. It respects all part of the building design both aesthetic and technical and therefore a recommented approach for further passive house design. To make it work the circumstances need to there. This study has showed the importance of:

- actors adapt expectations and agree about the goals and aim,
- establishment of interest in each others field of specialisation,
- and including the different expertise in the design process from the beginning.

It is believed that we are on the way towards more integrated approaches, but there are still barriers, which to some extend is far from being broken down. The institutions are still educating specialised candidates and thereby missing the general understanding of different way of reflection-in-action. Therefore architects and engineers do not want to intrude on each others domain. But the increased level of complexity in passive houses and low energy houses, which also affect the architectural expression, needs other expertise earlier in the process than conventional housing. The actors in the building industry simply need to gain trust in each other (Brunsgaard et. al 2010b).

7 Architecture and everyday life

7.1 Introduction and aim

The homes of the future need to be designed in a way that the occupants can relate to them and live their lives comfortable in them. Therefore, it is necessary to achieve knowledge and experience about the architecture, the life and user behaviour and user needs in low energy buildings in order to optimise and improve the next generation of low energy homes. Previous examples of low energy buildings in Denmark have been represented by more alternative and odd looking buildings, e.g. Villa Vision and Friland, Figure 41 and Figure 42 where certain behaviour and/or technology is required. In order to become a success, it is believed that the future low energy houses should be something recognizable and attractive and maybe not so different from what the Danish population are used to.

Figure 41: Villa Vision, Development project by the Danish Technological Institute, finished in 1994. It is a round house with a sun space in the middle. The solar shading is triangular sails that become a characteristic expression of the house (Moltke et al. 1997).

Figure 42: Friland, Djursland – is a self-builder area in Denmark where they focus on energy use, natural and recycle materials, wastewater cleaning etc. The self-builder area was founded in 2002 (www.fbbb.dk).

The focus of this study is to communicate how the occupants of the Comfort Houses experience the passive house architecture and technical services systems as well as to illustrate if their life and everyday practices have changed by moving into a passive house. Furthermore, this work will illustrate how the occupants use the house and if the house meets their needs and wishes. This knowledge can facilitate the future production and use of Danish passive houses because the occupants are seen as representatives of the target group of this type of houses and they will represent the future occupants or owners of passive houses. This study will answer the second research question:

How do the occupants of the Comfort Houses experience the passive house architecture and the technical service systems? And has their everyday life changed by moving into a passive house? If so, how?

Originally the idea was to sell the houses on the normal housing market but at the time of completion the financial crises occurred and the real estate market died. Because it was not possible to sell the houses they were rented out. Fortunately, it was possible and this study is based on three of the cases - case 2, 7 and 8.

This chapter presents the main theories, results, discussions and conclusions. A more thorough review of the study can be found in *Occupant Experience of the Everyday life in some of the first Passive Houses in Denmark*. Brunsgaard, C. et al. (2010c). I : Housing, Theory and Society (Appendix A).

7.2 Theory

To enlighten the everyday life of the occupants and the changes they have gone through, theories of everyday life sociology is used. Theories of Alfred Schutz (Schutz, 2005) supported by theories of Birte Bech-Jørgensen (Bech-Jørgensen, 1994, 1997 and 2002) are used in this research because they depart explicitly in the everyday life and analyse its' principals. The work analysed within the concept of common sense which is a kind of natural attitude which can describe the life - how it seems given and natural. A way to work scientific within common sense Alfreds Schuz state that to be able to understand the subjective opinions, scientifically designed models of a part of the social world should be defined. The models are designed patterns of typical course of action that are relevant to the investigation – therefore all irrelevant is removed (Schutz, 2005). To be able to "measure" the everyday life of the occupants, models of certain experiences or courses of actions in the Comfort Houses are described. The models are then investigated by what Birte Bech-Jørgensen calls the double perspective. The everyday life has to be observed from the conditions of a certain everyday life (perspective 1) and how the people manage the everyday activities according to the conditions (perspective 2) (Bech-Jørgensen, 2002). More reading about the theoretical foundation can be found in the scientific article in Appendix A.

7.3 Comparative study of the three cases

The models make it possible to "measure" if the houses function as they were planed and if the residents have changed practices in their everyday life by living in the Comfort House. First, the models reflect the everyday practices that are connected to the building concept of passive houses. Regular everyday practices like cooking, laundry and cleaning are not directly interesting because they are expected to stay the same whether you live in a passive house or in a conventional house. But everyday practices like ventilations and solar shading practices, regulation of the temperature, living behaviour with transparent/ opaque facades etc. could change by moving into a passive house compared to living in a conventional house. Secondly, the models are developed from the myths and assumptions in the building industry about how it is to live in a passive house and what potential problems that could occur. The findings will be presented in themes of the models and compared cross cases.

The results of each interview shows that the everyday lives of the occupants in the Comfort Houses have undergone some changes during the first period of living in the houses according to the models. More details about the model and result of each case can be found in *Occupant Experience of the Everyday life in some of the first Passive Houses in Denmark*. Brunsgaard, C. et al. (2010c). I : Housing, Theory and Society (Appendix A). In the following a comparison and discussion of the result of the three cases will be presented.

Qualities and problems of the Comfort Houses

There is a tendency that all cases are overall satisfied with the architecture of the houses especially in relation to the open plan solution which supports the family in being together in the home, and satisfied with the interrelationship of the functions and rooms. Additionally, most cases mention the nice daylight in the family rooms and views from the houses. The occupants could choose between all the houses and therefore pick the house they liked the best and had the qualities they liked. However, it might illustrate that the common areas, the layout of the house and the view and daylight are the most important qualities for them and that the design teams have succeed in fulfilling the overall needs of the architecture. The problems they point out are more varied and maybe more interesting to investigate. Has the problems anything to do with the fact that the houses are passive houses or is it "normal" problems which also could occur in conventional houses as well? One problem which could be a result of the passive house concept is that some would like more daylight in some rooms which are facing north. The lack of daylight can be a consequence of trying to minimise the heat loss through windows. Windows facing north only contributes negatively to the energy balance. The other problems are more individual and specific for each case. Lack of storage and shelter in the outdoor areas and poor quality of workmanship has more to do with the design, construction and economy of the house, than directly the passive house concept. This does not make the problems less important, it is just problems which also could occur in any other projects and therefore of little interest in this study.

Transparent/ opaque facades

The three cases had varying experiences with transparent facades to the south. One case needs to close their blinds often to fell private, another case only close them sometimes, where the last case do not care at all if anyone looks into their home. Comparing the context of the house with their experience it is possible that the feeling of being exposed is dependent on the context, see Figure 43. If the house is pulled back from the street and the neighbour in front has a more opaque facade orientated to you, the need of creating privacy decreases. Of course the amount of plants and trees also has an affect. All houses have limited plants in the surroundings, because it is a newly developed housing area. Nevertheless, in two of the cases the families have started to get new everyday practices by using the blinds or curtains to create privacy. The question is, if we just have to accept those practices and *"feel a little box-like inside"* in the future or if the privacy aspect to a greater extent needs to be taken into account when designing future passive houses. The focus has to be on both placement of the house according to neighbours and street, but also to the design of the outdoor areas with plants and trees. Regarding the experience of the more opaque facades to the north they do not mind that the façade are less transparent. They of course like the view to the north, but it does not seem like a large problem – other factors like privacy makes it less important. It can be questioned if the window areas to the south are much larger in passive houses than in conventional new single-family houses today. There is a general tendency to have relatively large glass facades especially facing the main outdoor areas which mostly are placed to the south or west of the houses in Denmark. Therefore the experiences of the occupants could be a general response to take into account when designing single-family houses in the future. Nevertheless the south orientated windows are principally a necessity to achieve passive solar heat gains to be able to fulfil the passive house criteria.

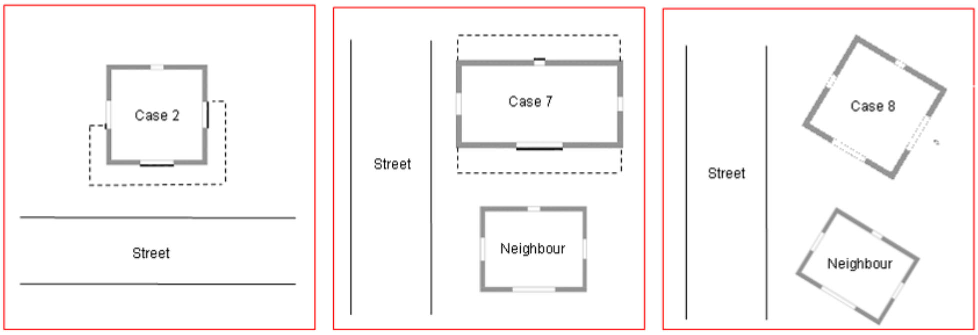


Figure 43. The diagram show the concept of how the houses are placed in relation to the road and to each other. The windows are conceptualised by putting the windows together as one, but they are fit with the right percentage of the façade. The dashed line in front of the window indicates the overhang. The overhang does only shade the windows in mid summer and only at midday. It means that the morning and evening sun come through the windows.

Excess temperatures

Compared to the occupants' everyday life in the previous home all cases have undergone changes. The conditions were different in their previous home, because they did not have any problem with overheating. A life in a Comfort House (based on these tree cases) forces the occupants to be more aware of natural ventilation and solar shading and they need to take action to ease the problem, however they are still very dissatisfied with the thermal indoor environment. If this should be changed in future passive houses, it is necessary to look at the design and design process behind the house and focus on how to minimise the risk of overheating. It is not possible to point at one aspect that would solve the problem, it could be several and maybe in a combination. Examples could be: generally optimise the solar shading and maybe add automatic control as seen in lots of German passive houses today. Or optimise the design of the natural ventilation. Or give better information to the occupants of how to live in a passive house and what consequences different behaviours have. Or maybe the most important approach, which is to analyse and document the indoor environment of the design proposal through the design process with calculation and simulations to find out what initiatives would fit the individual project the best both technical and architectural.

Passive house windows and the wide embrasures

None of the tree cases see the wide window embrasures as a problem; in one case they actually think they are usable for other purposes, but unfortunately they do not use them because of the lack of comfort caused by too much solar heat gains. Another case has hardly noticed the deeper embrasures. These different readings can have a connection to how the window have been built into the wall; in the middle, far back or aligned with the outer wall, e.g. the windows placed in the middle of the wall do not expose so much internal embrasure and therefore it does not look much wider than “normal”, see Figure 44. The size and placement of the windows can also have an influence on the experience of the embrasures. If the windows are put together in larger section and they are made as floor-length windows, it does not show the wide embrasures as much as smaller windows with window sills. This might illustrate the design teams’ awareness of the challenge with the wider embrasures. This study shows it has resulted in satisfying solutions for the occupants. Regarding the wider frames of the passive house windows, the two cases where the frames are wider than normal windows, they do not experience that as a problem. It could be because the occupants in the two cases have another nationality then Danish and maybe more used to wider frames than people with Danish nationality. But it could also show that the aesthetical aspect with the slimmer look of the window frame is not as important to the occupant as it is to the architects.

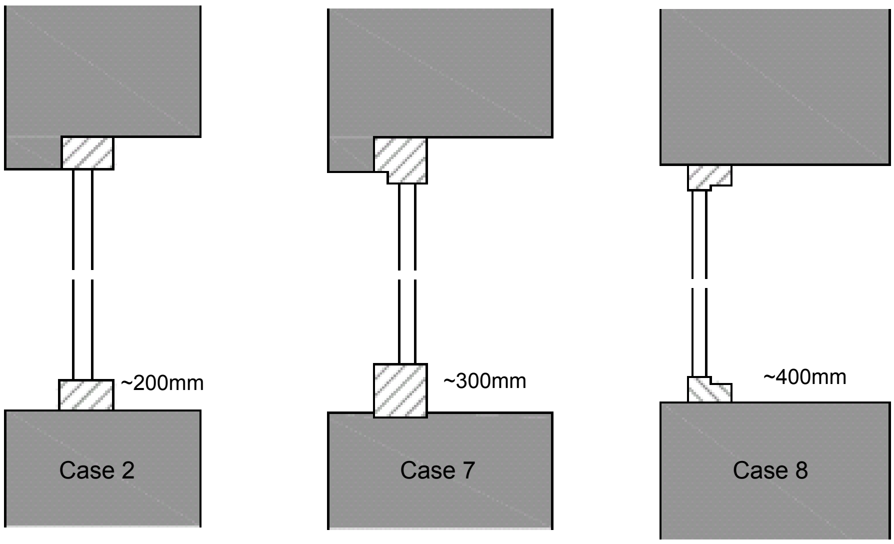


Figure 44. The illustration shows the different window solutions.

Ventilations habits

The three cases show three different responses to how it is to live in a house with a mechanical ventilation system. One does as they are used to, an other one have got new habits – habits that follow the way the passive house technique was thought and finally a case where they try to follow the idea of the system, but it does not satisfy their needs and they supply with natural ventilation. The latter might have something to do with the fact that three out of four occupants smoke in the house and they need a high air change rate. But the question is why the three cases have different experiences and habits with the ventilation systems. The controls of the systems are a little different in each house and some could be more user-friendly than the other and result in a different use, but an important thing could be the lack of information and “education” about how to handle the ventilation systems and the consequences of different behaviours on both the indoor environment and the energy use. All the occupants have got very limited information about the technology and the use of a passive house, mostly they have acquired the knowledge step by step, when technicians or the owner of the houses have been in the house to install or correct something. A better introduction to the passive house and heating and ventilation system e.g. through a manual, could have given the occupants a better understanding and thereby more trust and courage to using the ventilation system “correct”. The question also arises, if the idea behind the passive houses regarding the ventilation can become a part of the Danes everyday life? It needs to be, because the ventilation system with heat recovery is one of the essential aspect of minimising the energy use in buildings, therefore it is not expected to see future low energy houses without it. Therefore it is important to focus on the user-friendliness and the information about the systems to the users. Or maybe the systems have to be more automatic? But is it all right to turn the occupant into passive inhabitants with no knowledge? This paper cannot answer these questions but the situation possibly has to be evaluated in each case. It is imaginable that some groups of occupants or landlord would prefer a more automatic system in e.g. social housing, where others like e.g. private owned single family houses prefer more self control.

Regulation of the temperatures

All case would like to have a greater possibility to regulate the temperature individually in every room and two cases actually do not trust that the system deliver the heat that it should. If this is compared to the situation they are used to, were all had radiator heating in each room, it shows that their freedom has been taking away from them and now they have to rely on the technique. Before they just turned up the radiator if they were cold, therefore the situation today has given the occupants more trouble in their everyday life than they are used to. Now they either do not know what to do and put cloths on or call a plumber. Is this how people should live in a passive house in the future? Even taking into account beginners problems with the heating in case 2, the possibility of regulating the temperature in the individual room was not there. This show that the original idea about heating up the house with ventilation air regulated from the central aggregate is too restricting for the occupants. Therefore this study might show that we have to go back to some solutions that the occupant already knows e.g. heating up with radiators or floor heating with individual temperature controls. This tendency is also seen in German passive houses today even though the original ideas of saving the expenses in the extra installation disappears (Personal communication with Troels Kildemoes from the company “Ellehauge og Kildemoes”).

7.4 Comparative study between the Comfort Houses and other passive houses

Because this study only is based on three cases it can just give us a hint of how the occupants of a Danish passive house experience the architecture and live their everyday life in the houses. Additionally, it can be discussed if the time the occupants have lived in the houses before the second interview has been long enough (between six to ten month). To strengthen the conclusion some of the results are compared with the results from other research projects with similar studies.

The first project is a part CEPHEUS – Cost Efficient Passive Houses as European Standards (Feist et al. 2001 and Schnieders, 2006) The houses was built in Kronsberg, Germany and was evaluated to assess the occupants’ behaviour and management of the different technical elements (Danner 2001). The second project is an investigation of the first passive house project in Sweden - row houses in Lindås Park in Gothenburg. The research investigated how the occupants use the building and the techniques, in addition to how they experience and can influence the indoor environment (Boström et al. 2003). The third project is also from Lindås Park but part of another research project. The objective was to find out how the occupants use, choose and relate to the technique of the heating and ventilation in the home, with the focus on domestication (Isakson, 2009). Each of the projects is further described in *Occupant Experience of the Everyday life in some of the first Passive Houses in Denmark*. Brunsgaard, C. et al. (2010c). I : Housing, Theory and Society (Appendix A).

The results from the Kronsberg project showed that the occupants were satisfied with the thermal environment in the summer, but 40% of the housing unites has invested in additional shading devises and many supply with night ventilation to become satisfied. It is similar in Lindås Park, where they also felt too hot in the summer. About half of them have installed external shading and supply with natural ventilation. In the Comfort Houses they also feel too hot. All three cases in the Comfort Houses have installed internal shading, but that is not as efficient as the external. Besides that they supply with natural ventilation, but here the openings in some cases are made in a way that they cannot be left open when the occupants are not at home. As the situation is today the occupants just have to live with the excess temperatures, but maybe they might install external shading or air conditioner which two cases expressed could be a possibility. It tells us that external shading is an aspect that needs to be improved and needs a greater focus when designing future houses.

The ventilation routines, regarding the air quality in the German and Swedish studies, show as diverse results as the case of the Comfort Houses. In Kronsberg they had no problem adapting to the systems, in Lindås Park some occupants got more and more confident, where others were afraid of the technology. This can be very dependent on the kind of system and the user-friendliness of the technology and finally depend on the information, manuals or “education” they have had about heating and ventilation systems. It becomes clear in all the studies that information about the passive house and the technique is very important. This supports the discussion of how the experience with the ventilation system could have been more positive in the Comfort Houses if they have had more information about it.

The control of the thermal indoor environment in the winter period highly depends on the ventilation system and the solar heat gains. Both the study of the Comfort Houses and the other studies show that you need to get used to not having the possibility to regulate the temperature in each room and most occupants experience uneven temperature in the rooms because of solar heat gains, nevertheless some occupants in Lindås Park think it does not matter because they can light candles and it will heat up. If that is a sustainable solution in the long run can be discussed. Maybe we need to go back to heating up the houses with more controllable techniques e.g. radiator which people already know. Because, can we accept to live in a house were there are uneven temperatures throughout the house? Is that comfort? If we want to sell the houses as comfortable houses and not just as passive low energy houses, it is believed that this is not acceptable.

7.5 Conclusion

Regarding the time aspect between the two interviews of the occupants, an extra interview after maybe one more year in the houses would show if they still have the same everyday practises or if they got new practices. Topics, in which a longer period of time in the houses could have affected the results, could be in relation to the ventilations and heating practices. Maybe the occupants who were afraid of heating and ventilation systems have got more knowledge and courage to use the system after more time in the house. The other everyday models are more dependent on the architectural and structural solutions and unless the occupants are changing them, their experiences and practices would possibly be unchanged. But as the above comparison shows is there a fine agreement between the results.

Therefore it can be stated that the period of living in the house before the interviews have not been too short. And the results have given a good idea of how it is to live in a passive house maybe not only in Denmark, but generally.

This study field discussed how an everyday life of the occupant in a Comfort Houses can expect to be within the everyday models defined. Some of the expected changes in the everyday practices are both confirmed and disconfirmed and some are additionally verified with similar studies. The changes that are important to emphasise are:

- Curtain and/or blinds have become a part of the everyday practice of creating privacy in some of the cases.
- The occupants needed to get an awareness of the thermal environment and therefore curtains or blinds, plus natural ventilation is a permanent part of the everyday practices in the summer to reduce over temperatures.
- Some occupants have become worried about the air quality and do not trust the mechanical ventilation system and one case shows that it is possible to be very satisfied with the new system and functionality of it.
- The freedom of controlling the temperature in the houses has been restricted – a situation they just have to accept in their everyday life in these cases.

Additionally, the Comfort Houses' ability to fulfil the occupants need have also been outlined. Generally the houses fulfil the need of the occupant. Few problems are a result of the passive house concept, which are worth being aware of when designing future passive houses. Firstly the large windows to the south can create discomfort, because the lack of privacy to people passing by. Secondly single rooms to the north could have had more daylight and strengthen the nice view to the north. This shows that it is important the house is designed to the site and the context, were both pros and cons of the site like looks from people passing by and the nice view is taken into account.

If the passive house is supposed to become a success in Denmark and maybe also in other countries, it is recommended to be aware of the above mentioned everyday life practices in a passive house. The desired life of the future occupants or owners of a passive house need to be aware of the possible changes to their everyday lives. If this is not acceptable the condition needs to be changed and automatically the way the occupants manage those conditions will result in another everyday life confer the double perspective of Birth Bech-Jørgensen. Through the discussion different suggestions to how to change the conditions are presented. Maybe we have to go back to some of the technologies we know or maybe find some compromises, so it is possible to design passive houses that fulfil the occupants' needs and allow them to have freedom and self control of the house and still fulfil the energy demands of the future. Therefore information and knowledge about both the technologies and the way to act in a passive house (or any other low energy houses) is important for this concept to be a success both for the occupant and the environment (Brunsgaard, C. et al. 2010c).

8 Indoor environment

8.1 Introduction and aim

The build environment accounts for about 40 % of the energy use in the EU an it is the consequence of an effort to give the building users a best possible indoor environment by good ventilation, comfortable temperatures and sufficient light. New buildings and renovation projects need to improve the energy performance and in the process of doing so, it must not be on the expense of the indoor environment.

The purpose of this study is to evaluate the indoor environment through both quantitative measurements in the houses and qualitative interviews with the occupants about their experiences of the indoor environment in the house. Both approaches are taken because they give two different kind of knowledge. Knowledge that together give a more complete and holistic picture of the indoor environment since one set of results can be further explained by the other. The study presented in this chapter answers the following research question:

To what extent do the Comfort Houses live up to a comfortable indoor environment? How do the residents of the Comfort Houses experience the indoor environment and the possible adjustments of it? And how does the experiences relate to the measured indoor environment?

The quantitative measurements are a part of a demonstration project: *Demonstration of energy use and indoor environment in 10 Danish passive houses* (Demonstration project 2009, web) which is focusing on energy use, thermal comfort and indoor air quality, daylight conditions and acoustical climate. This study focuses on the indoor environment part and leaves out the topic of energy use. The results will be based on three of the eight houses, as the remaining houses were unoccupied at the time of this evaluation – case 2, 7 and 8.

In the following some of the main results will be presented. The full comparative study can be found in *Evaluation of the Indoor Environment in the Comfort Houses - Qualitative and Quantitative Approaches*. Brunsgaard, C. et al. (2010d). I: Indoor and Built Environment (Appendix A).

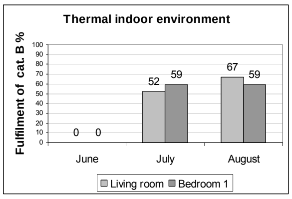
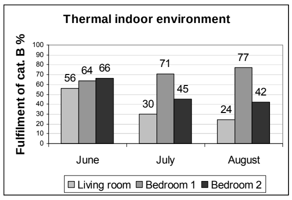
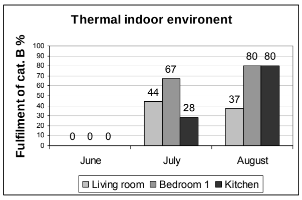
8.2 Results

8.2.1 Thermal indoor environment

The thermal indoor environment in the summer is poorly fulfilled in all three cases, especially in the living rooms. The measurements show that there is a tendency of excess temperatures and case 7 decidedly does not meet the comfort requirements, see Table 9. One explanation could be that case 7 has not used the summer by-pass in the ventilation unit. The conditions are also exemplified in

Figure 45 showing the indoor temperatures in the living room in July. The occupants in all three cases confirm in the interviews that the indoor environment is too hot in the summer and that they tried to solve the problem by installing blinds and using natural ventilation.

Table 9: The thermal indoor environment in the summer period – June, July and August.

	Case 2	Case 7	Case 8
Measurements		 Comments: Very high temperatures (temp.). Average temp. in the period is approx. 26°C.	
Interviews	The occupants experience that it is too hot in the summer period in the house. They have installed internal blinds and try to further solve it with natural ventilation (vent.) and by wearing very light cloths.	The occupants experience that it is very hot inside. They try to solve the problem with natural vent., but it only helps a little, therefore they have thought of installing air-conditioning. They experience that heat moves around with the sun, it means it is very hot in the bedroom and the children's room when they sleep. They do not want to leave windows open in the daughter's room when she is sleeping, due to safety reasons.	The occupants experience that it is too hot in the house. They have installed internal curtains, but do not think it helps. The natural vent. does not work sufficiently either. The windows have trouble staying open because of the lock mechanism. Additionally, windows are not left open the planned amount of hours due to theft protection. When nothing helps, the occupants go out in the garage.

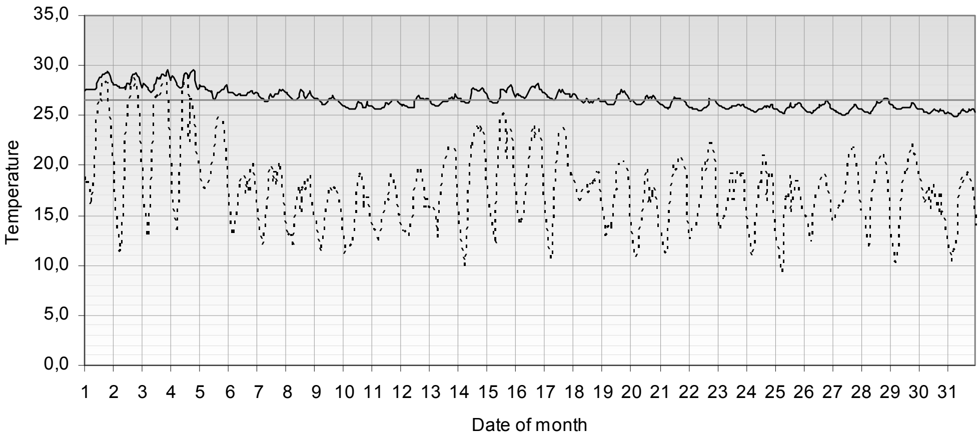


Figure 45: The full line illustrate the indoor temperature in the living room in case 7 in July 2009, the dashed line is the outdoor temperature. The indoor temperature do not drop below 25°C and the average temperature is 26,6°C (the thicker gray line).

The investigation also shows that the occupants' behaviour and psychological experiences have an influence on the resulting thermal comfort of the house. Maybe the house is designed well regarding the thermal indoor environment – confer the standards, but a different operation by the occupants can result in a worse indoor environment. It can be exemplified. Maybe the natural ventilation in the houses was designed to deliver a sufficient amount of air to fulfil the thermal indoor environmental requirements in summer, but if the designs do not fit with the psychological or social behaviour of the occupants the attempt will fail. On the other hand, if the natural ventilation should work sufficiently, the design also needs to be functional and manageable for the occupants within their practices:

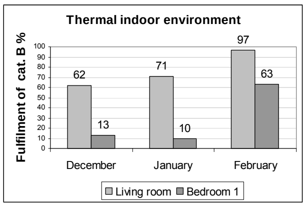
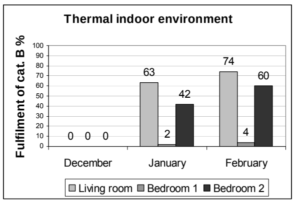
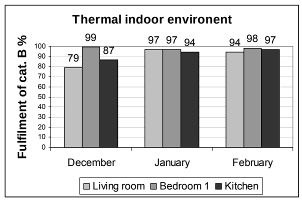
"…we could not keep the doors open when we are not home. That was what the idiot of an architect said we had to do (when we complained about the thermal conditions). Additionally, the windows must be open, but it is not possible – the windows can not stay open because they are not designed to stay open. They have a small screw you have to screw on and you have to do it every time ... And put the alarm on and leave the window open (when you are not at home), I do not think so." (Case 8)

Based on the above quote, the windows should be designed in a way that they can stay open when the occupants are not at home, without compromising safety. Or on the other hand, the dimensioning of the design needs to take into account that the natural ventilation only functions during occupancy, which mostly are after four o' clock in the afternoon in single-family homes.

Regarding the thermal indoor environment in the winter period, occupants in all three cases think it is too cold in the house. It can partly be verified by the measurement during the winter period, see Table 10 – partly because case 8 has fulfilled category B over 90% of the time in most rooms and months, which is evaluated to be acceptable, because a fulfilment of category B 100% is not realistic. In case 2 and 8 technical adjustments in January have resulted in a significantly better thermal indoor environment both measured and experienced. Especially in case 2 the percentages of time fulfilling category B increase significantly in the living room, where the problem was solved temporarily with an electrical heater.

The charts in Table 10 show significant differences in fulfilling category B in the different rooms in each case. The causal explanations of this phenomenon might be equivocal. Firstly the occupants describe in both case 2 and 7 that the extra bedroom is not used everyday. It might result in closing the doors to the rooms and the internal heat gains from e.g. equipment and people transport poorly to the room. Another explanation could be the lack of considering different transmission losses from different rooms and/or the lack of solar heat gains because of the orientation of the windows when dimensioning the ventilation system. Or finally the actual internal heat gains are lower than the theoretical ones used in the calculations in the planning phase. The occupants confirmed the experience of different temperatures in the different rooms. Two of the cases express a direct desire to regulate the temperature individually in the rooms, which in current state is not possible because the houses are heated up by the ventilation air and the temperature is controlled in the ventilation unit and not in each room.

Table 10: The thermal indoor environment in the winter period – December, January and February.

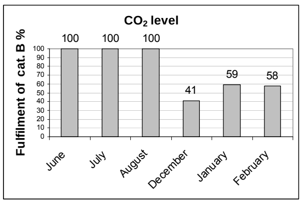
	Case 2	Case 7	Case 8
Measurements	 Comments: The heating problem in the living room was resolved in January 2010 with an electric heater of 500W (temporarily).	 Comments: In January and February in the early morning the temp. are just below 20°C, see figure 3.	 Comments: The technical installations were adjusted in January.
Interviews	The occupants struggle to stay warm when it is overcast. The temp. is often down to 17°C, so they have to wear skiing underwear and warm socks. After installing a radiator (temporary) and after they were informed not to naturally ventilate in the heating season, they did not experience any problems with staying warm. They think it is frustration not to be able to control the temperature.	The occupants think it is a little cold and they cannot get more than 20°C in the house when there is overcast. It's too cold to walk around in a T-shirt as they are used to (not standard cloths in wintertime according to standards). They think it is nice when the sun is shining, then the temp. increase 2-3°C. They experience different temp. in the different rooms when the sun is shining. Especially the daughter's room (not measured) was colder than the master bedroom (bedroom 2).	In the beginning the occupants had 19-21°C, which they thought was too cold, but after the inspection of the system, the temperature came up to 23°C. The occupants miss a better management of the thermal indoor climate – they experience different temp.

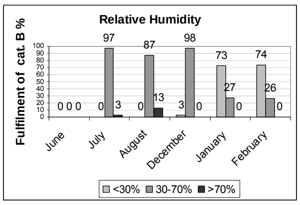
8.2.2 Indoor air quality

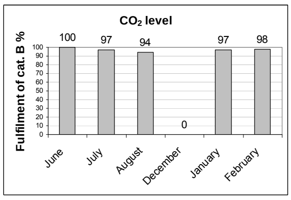
The charts in Table 11 show that there are no problems with the CO_2 levels in the summer period, whereas the fulfilment of the CO_2 levels in the winter decreases in case 2 and 8. This variation between summer and winter shows a normal pattern, which is due to the fact, that the house is more open during the summer period because of open windows and doors. The occupants in case 2 and 7 generally feel satisfied with the air quality, however case 2 supplies with natural ventilation in the morning.

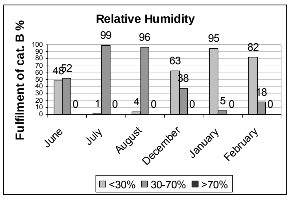
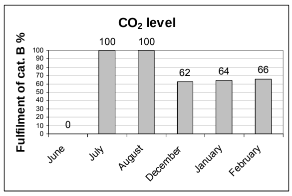
The occupants in case 8 on the other hand express more dissatisfaction. The situation is complex because a number of things are on stake. In the following some of the most central aspect will be outlined. Overall it is about the lack of knowledge, trust and communication.

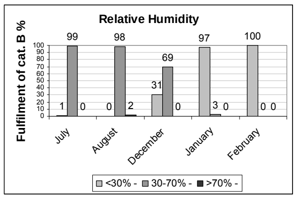
Table 11: The atmospheric indoor environment, CO_2 and RF in the summer and winter period in the living room.

<table>
<tr><td></td><td>Case 2</td><td>Case 7</td><td>Case 8</td></tr>
<tr><td>Measurements</td>
<td>



Comments: In January the ventilations system is changed to run at level 3 instead of level 2.</td>
<td>


</td>
<td>



Comments: In January the ventilations system is changed to run at level 2 instead of level 3.</td></tr>
<tr><td>Interviews</td>
<td>The occupants think the air can be dry in the winter, so they often sleep with open windows at night (increased air exchange will just lower the humidity even more). Otherwise they are satisfied with air quality. Even so they supply with natural ventilation in the morning like they are used to, because they think there is a need for it (It can not be stated by the interview if they continued doing so after the air exchange was increased).</td>
<td>The occupants think the air is fresh and healthy and not at all humid or heavy. They think it's great to live with a mechanical ventilation system, because they do not need to open the windows as they did before. Previously, they could smell that they had to open the windows in the morning. Today they sometimes use the ventilation system actively, e.g. when the wife cooks and they have people over they turn it up. They think it is very easy because they just have to press one button and the air change becomes higher in one hour. After one hour, they can press the button again.</td>
<td>If there is only one person at home the occupants do not think the air in the house is heavy, but with five og six adults, the air becomes heavy in a few hours. They want a high air exchange rate in the house – so they cannot see or smell that they are smoking in the house (to achieve that, the air exchange rate have to be about ten times higher). They feel the ventilation system is not running correctly. The occupants think, they have been more ill in the new house – it is very dusty and their noses are blocked. They supplement by natural ventilation both summer and winter.</td></tr>
</table>

Firstly the service man of the ventilations system gives the occupants wrong information and it is exemplified in the following interview dialog:

… Interviewer: *"Does this mean that you ventilate extra by natural ventilation?"* Occupant: *"We have to do so – three to four minutes each hour and that is when the ventilations system runs on step 4. It is because it is so hot in here."* Interviewer: *"Do you also ventilate extra by natural ventilation in winter?"* Occupant: *"Yes, yes, because we only had the ventilation system running on step 2, as they (the service man) said we should. It should not run on a higher level than step 2, because otherwise the heat can not keep up."* Interviewer: *"Why do you have a need to open the windows in winter?"* Occupant: *"There air quality is poor in here ... we needed some fresh air. But it should not be necessary when you have a ventilation system."* (Case 8).

The service man is not well informed about the ventilation and heating system, because the system should be able to produce heat no matter what step the ventilation system runs at, as long as it is designed correct. The occupants think the performance on step 2 results in poor indoor air quality and therefore they react by using natural ventilation to improve the conditions. However, this results in lager heat losses than if running the ventilations system at step 4, because the fresh air bypasses the heat recovery in the ventilation unit. Then the ventilation system needs to produce even more heat. This shows lack of knowledge on two levels. The service man misinforms the occupants, because he lacks knowledge about the system. And the occupants are not familiar with the principals of the heat recovery in the ventilation system. He is familiar with natural ventilation as the source to fresh air. Another aspect on stake is the mistrust to the mechanical ventilation system which the statement in above dialog shows among other statements, see more in the article in Appendix A (Brunsgaard 2010d).

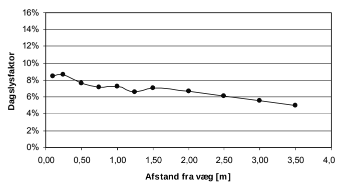
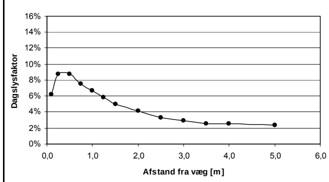
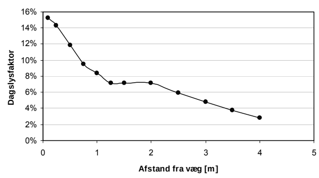
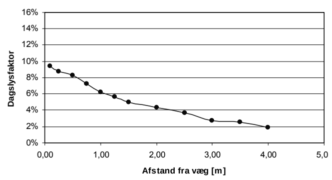
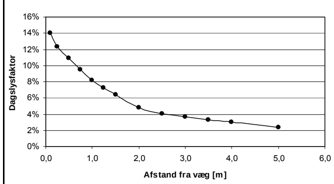
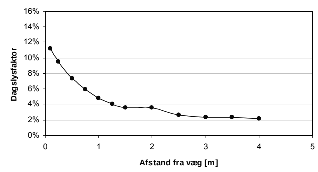
Regarding the humidity all measurement shows that it has been dry in the winter period. It was expected that the air will dry out, because the outside temperature during the winter has been very low and contribute to dry air inside. Case 2 is the only case that actually has experience the air being too dry; they “solve” the problem by opening the windows at night – a solution that just increase the problem. Again, the occupants do not have sufficient knowledge about the indoor environment – the thermal dynamics - and act contrary to the principals.

It can be contradicting to solve both the problem with too high CO_2 levels and the low humidity. The CO_2-level can be reduced by increasing the air change, but then the relative humidity will decrease even more. Adding moisture to the ventilation air can create other problems with e.g. mould in the system, which the building industry has a great resistance to. What is important to be aware of is that this problem will also occur in “normal” houses, with the same air change.

8.2.3 Daylight Conditions

The daylight conditions have been measured in two different places in the common rooms of the three cases. The graphs in Table 12 show that all cases fulfil the requirement of minimum 2% daylight factor, even in the back of the room. It means that the overhang of the houses does not have a negative influence on the daylight conditions, and the depths of the living rooms are suitable. The experience from the occupants fits very well with the measurements. In case 7 in the dining room an opposite window in the kitchen improves the daylight factor considerable. Additionally the living room is relatively narrow.

Table 12. The table lists the daylight factors of two different positions in the common rooms and the description of the occupants' experience of the daylight.

	Case 2	Case 7	Case 8
Measurements	 Daylight factors of case 2 in the dining room (south-north direction).	 Daylight factors of case 7 in the living room (south-north direction).	 Daylight factors of case 8 in the dining room (south-north direction).
	 Daylight factors of case 2 in the living room (south-north direction).	 Daylight factors of case 7 in the dining room (south-north direction).	 Daylight factors of case 8 in the living room (east-west direction).
Interviews	The occupants respond positive to the daylight conditions, even though the black coloured blinds sometimes takes up the daylight.	The occupants are satisfied with the daylight conditions.	They are satisfied with the daylight conditions and also state satisfaction with the living room situated in the north-east corner of the building.

8.2.4 Acoustics

The noise and experience of sounds is the last topic of the indoor environment to be presented. The measurements show that none of the cases live up to class B regarding the reverberation timer without furniture, see Table 13. How the result would have turned out with furniture is hard to tell. It depends both on the kind and the amount of furniture in the room, which can differ in each case. Instead the measurements are more comparable without furniture. In case 7 and 8 it is doubted that the reverberation time would be lowered to 0,6 seconds solely by adding furniture in the room. Case 2 on the other hand might fulfil the requirement with furniture.

As seen in the table simple calculations of the reverberation time based on Sabine´s formula (Valbjørn 2000) gives a very good indication of the reverberation time compared to the measured. If calculations like this have been conducted in the design processes others and better solutions might have been selected. On the other hand, if the demands in the tender document have been defined more clear, the focus in the design team would possibly have been larger.

Comparison between the measured results and the interviews shows that there are good correlations. Case 2 and 7 has the lowest reverberation time and none of the occupants complain about the sound in the rooms.

Interviewer: *"How about the noise in the house? Is it ok or could you use some more absorption of the sound?"* Occupant:*"No, I think the sound is ok."* Interviewer: *"It is not too dead or - ?"* Occupant: *"No, it is just perfect."* (Case 7).

Table 13: The table lists data from both the interviews, the measurements of the noise from the ventilation system, the reverberation time in the living room and the theoretical calculated reverberation time, based on Sabine's formula (Valbjørn 2000). Furthermore, the acoustical initiatives of the three cases are presented by pictures.

	Case 2	**Case 7**	**Case 8**
Acoustical initiatives in the living spaces	 Acoustic plaster	 Lists	 Squares with perforate acoustical plates
Average measured reverberation time (125-4000Hz) Without furniture.	0,79	1,23	1,40
Average calculated reverberation time (125-4000Hz) Without furniture.	0,59	1,77	1,38
Noise from the ventilation system (Measured on standard operation, step 2).	≤ 25dB	≤ 25dB	≤ 25dB
Interviews	The occupants experience a good acoustic condition in the house, but they experience noise from the ventilation system when it runs at step 3, therefore they turn it down to step 2.	The occupants think the acoustical experience in the house is perfect, with no echoing or dead sounds. They do not experience noise from the ventilation system.	The occupants experience a very bad acoustic in the house and it disturbs their everyday life in the house. They experience noise from the ventilation system if it runs on the highest step (4), which they prefer, but when music and TV is running they cannot hear it.

In case 8 the highest reverberation time is measured and the occupants are also the most dissatisfied, illustrated in following quote:

"This is the noisiest (house) I have ever lived in. The room up there, if I fart, you can hear it all the way down to the living room. It's so crazy. It is the same the other way around. ... It is totally poor, very poor. All the plates there (perforated acoustical plates) ... they do not work ... they have never worked ... the sound here – yeah you can indeed hear it now. Even though we have pictures and flowers, which should break the acoustic – it does not break… It's actually quit annoying.

You can not sit anywhere and talk without disturbing the rest of the house.” (Occupant, Case 8.)

The measurements of the noise from the ventilations system show that all cases fulfil the demand of 25 dB or lower in standard operation – step 2 (the exact value is not listed because the meter can not measure lower than 25dB). Even though cat. B is fulfilled the occupants in case 2 experience noise from the ventilation when it runs on step 3. The occupants therefore turn it down to step 2. The occupants in case 8 run the ventilation system on step 4 in the summer. They feel disturbed when music or TV is turned off.

8.3 Discussion

Overall, the study shows that the occupants’ experiences are consistent with the measurements of the indoor environment and that about half of the topics investigated after all fulfil the demands. The concept of passive houses is new to the building industry in Denmark and the pilot project of the Comfort Houses is one of the first proposals. Because these cases did not fulfil the comfort level better than they did, it does not mean that it is a bad idea to construct passive or low energy houses. Instead we have learned from these pilot projects and can improve the next generation of passive houses.

The fact that the CR 1752 [11] (developed to offices buildings) is used to evaluate indoor environment in housing means that we have to be careful with what we conclude. The comfort level of the occupants in housing is often much more individual e.g. some wants 20°C in the living room where others prefer 23°C or some wants a cold bedroom where others wants a warm. During the comparative study between the three cases different problems have evolved mainly because the interviews have been highly helpful to explain some of the measured conditions. Despite that the occupants can have been influence by the measurement equipment, the occupants' opinions are still important to get a more detailed picture of the indoor environment, since measurements usually only explain how the situation is, the interviews can explain why it is as it is.

Initially, we have seen design related problems which are dependent on the design decision made by the design team, which in these cases are cross-disciplinary design teams. Two reasons can be identified to have an influence on the design decisions. Firstly, the demands to the comfort in the Comfort Houses have not been fully clear in the tender document and therefore the design teams have individual approaches. Additionally, it is not regular practise in the building industry to document single-family houses in such details as discussed in this study. But if we want our future home to be comfortable and wants to call them Comfort Houses the building industry need to change practise and in a greater extend document the indoor environmental aspect e.g. by hour by hour dynamic simulations of the thermal indoor environment or calculate the reverberation time instead of selecting standard solutions based on previous experiences.

Secondly, the occupants have not been well informed about the conditions and assumptions for the system. If so they might have had different behaviours and maybe had more realistic expectations to the system and indoor environment of the house. Instead we have seen that the occupants behaviours and understandings of the indoor environment have a highly affect on the indoor environment. And we have seen that physiological and social aspect can be more important than the indoor environmental aspect. Some might argue that some of the indoor environmental strategies like natural ventilation, solar shading and air change rates need to be automated. But is that the way forward? Svenja D. Jaffari and Ben Matthews believe that the occupants instead need to become aware of their practises instead of becoming passive objects (Jaffari et al. 2009). They suggest more innovative solutions that confront the occupants with their behaviour and effect on the indoor environment instead of equipping the house with automatics. The interest in focusing more on the occupant and their behaviour and understanding of the energy and indoor environmental practices is further confirmed by Raymond J. Cole and others (Cole et al 2010). They think we need a broader view on comfort, because the concepts of buildings are evolving. They think occupants or inhabitants should become a more active and engaged part of the designing, maintaining and performance of the comfort – the indoor environment – instead of automating the building.

8.4 Conclusion

The indoor environmental quality found in these cases has showed that the qualitative and quantitative data correspond fairly well with each other. Even though the discussions have had a great focus on what has not worked in the Comfort Houses. The results shows that over half of the areas presented fulfil the comfort level defined in this study.

The areas were the indoor environment is not fulfilled is the most interesting because it is from them we can learn. Learn how to design the next generation of Comfort Houses even better. The experience from this study states four different areas – recommendation, which need more focus in future design and construction of passive houses/Comfort Houses in Denmark:

Firstly, it is important to define from the beginning the goals and demands of the project, to both energy performance and indoor climate, so the design team know what to aim for.

Secondly, the design process needs to contain sufficient analysis that can predict the indoor environment of the house, which could be other and new analysis than housing designers are used to.

Thirdly, it is necessary to have a greater focus on the occupants' life and behaviour when designing, dimensioning, planning and designing the control of the systems. The user-friendliness is one way for the occupants to handle the systems correct.

Fourthly, it is important to inform, educate and communicate to the occupant how to live in a passive house (or any other low energy house). Knowledge and communication is a source to gain trust in the concept from the occupants.

Finally, the building concepts need to be more robust so the houses become better to handle "ignorant" and difficult occupants.

This study shows the experiences with the indoor environment in some of the first passive houses in Denmark. Hopefully next generation will learn from this, because the future houses have to save energy and in the process of doing so, it must not be on the expense of the indoor environment (Brunsgaard et al. 2010d).

9 Comparative study – across study fields

The overall research question: *What can the experience from the Comfort Houses enlighten about the future production and use of Danish passive houses?* will seek to be answered and discussed in the following chapters.

The result of this research has been carried out by several kind of analyses based of several kinds of data, that has involved different kind of actors, which illustrate the interdisciplinary research area this moves around in. The Comfort Houses has been followed from the first concept to the final design by participating in workshops with the consortiums and by interviewing seven consortiums about the design process. It resulted in speaking to architects, engineers and contractors and sub-contractors all in all twenty-five people. All seven interviews have been transcribed and summarised and published in a technical paper: *Interviewrapport om designprocesserne bag ´Komfort Husene´* (Interview Report about the Design Processes behind the ´Comfort Houses´). (Brunsgaard, C. (2009a). Additionally, the construction process of the houses has been followed and at least twenty-five craftsmen from the building site have been interviewed informal. Thousands of pictures have been taken and used to communicate the project both in the book *Komfort Husene – Erfaring, viden og Inspiration* (Komfort Husene 2010), conferences, lectures and more. When the houses were finished families of three houses, represented by five people, was interview about both how they experience the architecture, how their everyday life is in the house and how they experience the indoor environment. Ideally all cases should have been represented, but unfortunately that was not possible, mainly because of the global financial crisis which affected both the construction and the selling of the houses. Luckily, some of the houses were rented out to regular families and it was possible to do the necessary investigations with tenants instead of owners of the houses. The occupants have been interviewed two times each – firstly about their life and experiences in their previous home and secondly about there experience in the Comfort Houses. These interviews have also been transcribed before the analysis. Additionally, there was made one follow-up interview by phone with the occupants of each house. Finally, the occupants' experiences was compared with measured data of the indoor environment, which evaluate both the performance of the house compared to the expected, but also the occupants behaviour and understanding of indoor environment. Later analysis of the energy use will be analysed, but it is outside the scope of this project. The above shows how this thesis has been approached in different part, which contains different types and quantities of respondents. The following will discuss how interconnected the main study fields are.

From design process to indoor environment

The analysis of how the consortiums have approached the design processes (Brunsgaard 2010b) showed a more integrated approach than the consortiums usually have and illustrate the importance of an integrated design approach when designing passive houses (Löhnert et al 2003 and Knudstrup 2004). Additionally, the analysis of the tools applied in the processes showed that it might be a problem for the resulting indoor environment, that the documentation was too scant: The daylight and noise environment was hardly investigated during the design process and the thermal indoor environment was only analysed by the average value of excess temperatures found in the energy calculation tool. Those findings were discussed to be imprecise in the journal paper *The Critical Design Process – Experiences from the first "Comfort Houses" in Denmark*. Brunsgaard, C. et al. (2010b). I: Architectural and Planning Research (Appendix A). Instead it should be replaced by an hour by hour dynamic simulation in critical rooms. The results of both the qualitative and quantitative studies of the indoor environment show that especially the thermal indoor environment in the summer period and the reverberation time was the biggest problems (Brunsgaard et al 2010d). The anticipation from the design process analysis was therefore confirmed. If the indoor environmental aspects had been better documented the problems might have been non-existing or at least they could have been minor. Some of the problems can be solved afterwards e.g. installing external solar shading, but that will most likely be *"add-on"* solutions that will influence the architectural expression of the house negatively, which is often seen today in the existing building stock when problems are solved after finishing. By working even more focus in the design process to design within a Danish or Nordic tradition of architecture and integrate energy and indoor environmental aspects during the earlier stages, we will come closer to design comfortable and aesthetic houses that function as expected. The different Comfort Houses have varying initiative both according to architectural solutions and more technical solutions like type of heating and ventilations system, control system, solar shading etc. Some solutions are expected to be more successful than others e.g. some of the houses have dynamic solar shading that are integrated in the architectural concept. Those are expected to be a good solution to prevent the problem of excess temperature. But unfortunately none of the houses with solution like that was occupied at the time of analysis, which means the study cannot make any scientific conclusion on the level of satisfaction of such solution. The analysis of the indoor environment also showed the resulting indoor environment can be affected by other aspects like user-behaviour in the houses or expectations to the user-involvement during the operation (Brunsgaard 2010d). But that is no justification; user-behaviour and user-involvement also has to be taken into account in the design process e.g. how often is it necessary to open the windows for natural ventilation – the whole day or only in the evening? Does that fit with the occupants' life and behaviour? It means the design team has a great responsibility in the design process – also if the client does not demand any goals to the indoor environment. The design team has to make the client aware of what his needs are; otherwise the design team does not know what to aim for in the process. The demands for the indoor environment in single-family housing can vary a great deal, where offices are more predictable, because there are more people in the same room and their behaviour is fairly known. The building industry today has no tradition in documenting the indoor environment in housing in the design process, but if the future residents should become more satisfied with their low energy homes and fulfil the comfort level it is a necessity, to take the above mentioned into account in the design process, according to these analyses.

From design process to everyday life

The resulting everyday life in the houses was investigated to answer the question of how the occupants experienced to live in passive houses. The study shows that parts of the everyday life are actually changed by moving into the Comfort Houses (Brunsgaard 2010c). Are there any interconnectedness with the design process, that it interesting for the future designers of passive houses? Yes, these cases has especially changed their everyday life as a result of the transparent facades (or larger amount of window area to the south), excess temperatures and regulation of temperatures in the individual rooms. All three aspects can to some extend be taken into consideration during the design process and different decision-making could have affected the outcome. The problem with excess temperatures has already been addressed above and will not be further discussed. The lack of privacy as a result of the large windows to the south, which some of the occupant experience, is concluded to be dependent of the placement and context of the house. To what degree it already has been a part of the decision-making this work cannot answer, but it should be a part of the design process. The house could have been orientated differently and the design of the outdoor areas could have created more privacy etc., which might prevent the occupants from closing the blinds and close off the daylight. The problem with the lack of opportunity to regulate the temperatures is indirectly a result of the decision-making. Indirectly because it is other circumstances that needs to be evaluated. Like predictions of how the indoor environment will be in the individual room with the chosen heating system and then take the precaution needed to fulfil the indoor environment. And evaluate how the occupants would live and control that. This might not have been considered in the investigated cases. Or maybe the design team simply had other expectations of how it would be handled, which means the system chosen for the houses might not be the future solution.

From everyday life to indoor environment and vice versa

The success of the Comfort Houses is very influenced by the operation and user-behaviour in the houses and thereby a part of the everyday life in the houses. Like stated in CR1752 (CR1752 2001) it is necessary to describe the design assumptions for the systems and the operational principals, and those conditions have to be met if the indoor environment should be as designed. It means that the user have to be warned that changes may result in another indoor environment. In this project they have not been informed about the assumption or principals which definitely has affected both the resulting indoor environment and everyday life of the occupants as the two article show: *Occupant Experience of the Everyday life in some of the first Passive Houses in Denmark*. Brunsgaard, C. et al. (2010c). I : Housing, Theory and Society and *Evaluation of the Indoor Environment in the Comfort Houses - Qualitative and Quantitative Approaches*. Brunsgaard, C. et al. (2010d). I: Indoor and Built Environment. Some of the occupants have been left with a lot of questions and acted “wrong” according to the assumptions made for the individual houses. But, as the article *Evaluation of the Indoor Environment in the Comfort Houses - Qualitative and Quantitative Approaches* (Brunsgaard, C. et al. 2010d) discusses, we do not know what the “right” indoor environment is in housing. We only have indoor environmental standards for office buildings confer CR1752. It is very individual what needs people have in their own homes. But what is certain is that the indoor environment affects the everyday life of the occupants and the everyday life affects the resulting indoor environment – they are interconnected. To expect that the consortiums have taken this into account in this project is may be too optimistic. Firstly, because it was a pilot project and some of the first passive houses built in Denmark, which means it was difficult enough for the design team to fulfil the energy demands. Secondly, the occupants of the houses were not known at the time of designing and could not be ask about their needs and wishes. But in future housing those considerations should be a part of the design process to be able to target for the individual needs.

The above discussions have showed the interconnectedness between the main study fields – an interconnectedness that have become even bigger in passive houses (or low energy buildings) than it is in conventional housing. The design of the building envelope have become more complex, the placement and context is more important, the houses has more technical service systems and needs a greater focus on indoor environment – all aspects that affect the everyday life of the occupants to some extend. The future (and present) design tasks have changed to be more complex and therefore needs more integration of the different fields.

10 Discussions

10.1. Implementation of recommendations in practice

Implementation in practice can be separated in two parts. Firstly, how can the recommendations be implemented in the existing design practice? Secondly, how can the occupants, residents, tenants etc. be informed/ educated about the new circumstances of living in passive houses?

Implementation of the majority of recommendations mostly relies on the design team. To be able to consider and integrate many of the new principals of passive houses and the recommendations found in this research project, it is necessary to have additional professional competences in the design process in earlier stages than traditionally. It means that engineers and architects and maybe also the contractors should have a closer cooperation through the design and construction phase of the houses. This will require a change in the mindset of the conventional actors in a design task and maybe the organizational structure of practice also needs to change in the future. Maybe the future organizations should have more competences in-house or maybe to a grater extend use Design Facilitators with interdisciplinary skills in the design development. A change in mindset is necessary because all actors needs to have an interest in constructing high quality housing both regarding the aesthetics, passive and active strategies within indoor environment and energy use, which at the same time respect the life of the occupants in the house. Therefore should the occupants also be highly involved in the decision-making. The changes in the industry do not come over night, as many companies still think of their own survival in the heavy competition in the building industry. The necessary integrated approach can offhand look like it cost more money, but it should be paid back in the end of the project, because of less problem-solving and changes to the design in late stages. As the actors become more and more familiar with the new approach they will see the benefits with this approach. It is difficult to "measure" positive effects of this approach; therefore it can be difficult to convince the actors of the building industry to change mindset. An in-house multi-professional staff will definitely meet the need for a higher level of trust and openness to each other. Additionally, the increased level of complexity is easier taken care of, because the communication between professions are strengthen by being in the same house – today barriers also lies in the physical separation of the different actors which to a greater extend support individual work flow. The high level of complexity has been illustrated in this research, but the approach to sustainability had been relatively narrow by focusing on energy and comfort, where it is imaginable that future project to a greater extend will focus on more aspects like e.g. LCA, energy production technologies, transportation, land and/or water conservation, toxic materials etc. They will increase the complexity even more and the integrated approach and collaboration between different professions become even more important.

The other part to consider in the implementation of the recommendations is the occupants. This research states that information or education of the occupants about how to live in a passive house is necessary to minimise mistakes and "wrong" behaviour. But whose responsibility is it? The client? But who will deliver the information if the occupant is the client? Maybe it should become a natural part of the "delivery" of the house – the product. Like when you by a DVD-player or a car you get a manual of how to handle and service the product. Each house has different strategies; therefore the design team has to make a manual for each individual project. This will be costly, but it is a necessity with the current passive house concepts. Some might say that the occupants will not read the manual. Maybe not, but if they have some kind of trouble they have the possibility to study a manual to understand the problem, which they do not have today in the Comfort Houses.

On the other hand, maybe the problem is not the education of the occupants; maybe the strategies and principals should be more robust and "idiot-proof" – if is possible. Or maybe it is actually a combination of information and development of robust and user-friendly solutions. Today the development is generally running very fast and technology has become a part of our homes and will possibly become an even bigger part in the future. Previous our home was something more static – the development was slower, which means we also slowly could get used to new things whether is was technology or things of more spatial and architectural character. That has change today; therefore information is a necessity and has to be part of the tender.

10.2 Generalisation, reliability and validity

As described in Chapter 2 (Methods and Theory of Science) the case study design do not aim for statistical generalisations, but relies on analytical generalisations, which means the results can be used to state a broader "theory" (Yin 1995) or as Steiner Kvale explains the results can be instructive for other similar situations. To be able to make analytical generalisations the researcher needs to provide sufficient documentation and argument for the generalisation of the results (Kvale 1997), then the "theory" or instructive results could be tested on other project, however that goes beyond this research project. The research of the *Design Process* contains all cases and gives a fine and broad set of knowledge, which supports many of the existing findings within the area. No doubt more cases in the study fields *Indoor Environment* and *Architecture and Everyday life* would have strengthen the conclusions or given more sufficient documentation about the phenomenon of passive houses. Unfortunately the financial crises came and did not allow the planed amount of analysis, but luckily some houses were occupied and most of them wanted to participate in this research project. The embedded multiple-case design was therefore based on three cases and it is believed they have some legitimacy especially because some of the findings are compared with other research project about the same topic from other countries, which has similar findings. Therefore the findings can be taken into account when designing passive houses in the future.

Reliability is about the consistency in the results. Robert K. Yin state that the investigation needs to be described so detailed, that it is possible for another researcher to perform the investigation again and get the same result (Yin 1995). Steiner Kvale arguments for the reliability on different levels: both when interviewing, doing transcriptions and analysing. He argues that even though it is desirable to avoid random subjectivity an enormous weighting of the reliability would neutralise creative renewals and diversity in the research (Kvale 1997). It means we should not be too fanatic because it can impair the research. Reliability in this research is also secured on different levels; when doing the design of the study, interviewing, doing transcription and analysing. Each study field is described in a thematization of the investigation and a common question guide is produced for the interviews in each study field. That secure that others can reproduce the investigation. All interviews and transcriptions have been done by the same interviewer, which secure a consistency in the data where different interviewers could have followed different trace in the interview. The analyses of the interviews on the other hand have mostly been done by one analyst (except from the support given by the supervisors affiliated to this work), where more analysts could functions as a control and give more rich analysis because of more perspective. In future research projects more researchers would be connected if possible. Additionally, the financial crises also affected the time planning of the different study fields. The study of the *Indoor Environment* and the *Everyday Life* in the houses had to be pushed to the end and combined in one interview, because it was important the occupants had lived in the houses both a summer and winter period. Ideally the two different fields should have been investigated separately to have a greater focus on the individual analysis. Instead the interviewer had to be even more focused during the interview and be aware of the two different objectives at the same time. The analyses of the interviews therefore had to be well organised to take care of a lot of data at the same time. This organisation was accommodated by the use of Nvivo software (www.qsrinternational.com), which supports the analysis when having a great amount of data and different topics to keep track of.

Validity of the research results is from a positivistic point of view defined as: *do we measure what we think we measure?* And often result in a set of numbers. A little broader understanding, in social science and humanism is: *does the method investigate what it serves to investigate?* Confer Steiner Kvale the validation take place on all stages of the knowledge production and cannot be placed at one stage in the qualitative interview. The seven stages are: Tematization, Design, Interview, Transcription, Analysis, Validation and Reporting. Examples of validation within those are: suitable methods compared to the objectives, the quality of the interview which include profound questioning about the meaning about what have been said, reasonable logic in the interpretation and more (Kvale 1997). The seven stages in Steiner Kvale's work have been followed in this research. Additionally, follow up interviews was done to further validate the results, because uncertainties or lack of answers came up during the analysis of the interviews. The qualitative interview is a workmanship (Kvale 1997) and therefore it takes time and experience to become a skilled interviewer. The necessity of the follow-up interviews can also be a result of that.

Validation is also about the quality of the workmanship, which has three aspects: control, ask questions to and theorise about the production of knowledge (Kvale 1997). The control of this research is done by putting critical perspective to the investigated together with dialog with the supervisors. Additionally, review of conference papers and journal papers, and participation on conferences contributed to the control of the results. Depending on what questions the researcher ask the material and theoretical understanding of the investigated it will result in different outcome (Brunsgaard 2010). Therefore this work made a big effort in defining the content and objectives before defining how to investigate the topics. To exemplify: in the study field of *Architecture and Everyday Life*, the first idea was to investigate architecture and lifestyle. But when describing the content and defining the objectives and theories it became clear that the notion and theories about lifestyle was not the appropriate view at the understanding of how it is to live in passive houses. The notion of lifestyle was often used to categorise a group of people based on different ways of living and making choices in their life, e.g. choice of car or newspaper which was not interesting in this research. Instead the clarification of the concept and profound analysis of the theories resulted in the notion of *Everyday Life*, which has more to do with the context and conditions and how the occupants handle those both noticed and unnoticed – theories that could be used to understand the changes by moving into a passive house.

Having addressed the aspects of generalisation, reliability and validity as regard to this research project and discussing the result presented in chapter 6-8 and the comparative study, an understanding of the Danish passive houses has outlined based on the project of the Comfort Houses. This research has produced knowledge, which results in recommendation of how to approach the future production and use of passive houses, which we did not have before. However, some might say that we already knew this or of course it is like that, but it would be based on rational thinking and not on scientific work. The results of this research are based on well defined research that have been carried out in the best way according to the conditions and circumstances and has taken the necessary precaution into account, which qualify the findings to be scientific. The analysis took-off in practise and the results needs to be taken back to practise to optimise the performance and life in the future passive houses in Denmark.

11 Conclusions and recommendations

The investigation of the pilot project of the Comfort Houses has given a range of knowledge about passive houses in Denmark. Additionally, the openness and the objective of sharing knowledge with all interested the project of the Comfort Houses has increased the awareness and given courage to the building industry to construct passive house. When the project started there were very few passive houses in Denmark, today there are about 150 unites according to Passivhus.dk (www.passivhus.dk). The knowledge from this research project has been a part of the knowledge sharing in the project and has been presented as the research progressed. The investigations of the Comfort Houses was divided into different study fields to gather knowledge that would form a holistic picture of passive houses and give a holistic understanding of how to approach passive houses in Denmark. In the following the findings or the recommendations for future production and use of passive houses will briefly be described.

The study of the design processes in the Comfort Houses showed that most consortiums have work more integrated than usual even without being introduced to any methodology of integrated design approach. However, that can indicate that the integrated design process is a beneficial approach when designing passive house, because it respects both technical and architectural aspect of the design, which all consortiums state is necessary (Brunsgaard 2010b). Despite the success with the process most consortiums do not document the indoor environment in the design process, which later studies show result in dissatisfactory occupants, which is believed, could have been avoided by more documentation. The study also showed that some circumstances are necessary to support the integrated design process: actors in the design teams have to adapt expectations and agree about the goals and aim and they has to establish an interest in each other’s field of specialisation. Finally, it has to be possible to implement the different expertise from the beginning of the design process. To be able to use a more integrated approach there are barriers in the industry. The majority of the educational institutions are still educating specialised candidates, who lacks of general understanding of different way of reflection in other specialisations and therefore architects and engineers do not want to intrude on each other’s domains (Knudstrup 2010). But the increased level of complexity in passive houses and low energy houses, which also affect the architectural expression, calls for other expertises than usually in the earlier stages in the process. An exception is the civil engineering education at Aalborg University, Department of Architecture, Design & Media Technology. They have for several years educated civil engineers with speciality in architecture – an architectural education that includes basic technical engineering skills that support the integrated design process (Knudstrup 2004 and Knudstrup 2010).

Experiences from the construction process showed that generally the construction of a passive house is not so different from “traditional” housing. E.g. the brick layers think their work is more or less the same, the space between the walls is just bigger because of more insulation. The foundation is just a little higher because the insulation layer in the ground is thicker. The part that has been the biggest challenges was the mounting of windows, both regarding the actual mounting in the wall without creating too big cold bridges, but also according to handling the heavy passive house windows. Additionally, several consortiums mention the importance of the communication from the design team to the craftsmen about the detailing of the house – the solutions have to be simple, so the craftsmen can imagine the solutions.

When studying the architectural expression of passive houses it shows that the basic passive house principles like compact shape, orientation of the larger window area to the south, good insulated building envelope etc. has the greatest impact on the architectural expression compared to the impact of the building technology, because the latter often is hidden in the constructions. One exception is the detailing of the windows which has more aspects to consider. A desk study showed that it is not enough to search for the optimum technical solution, like minimising cold bridges. It is also important to consider the architectural expression of the optimum solution to end up with a more holistic solution.

The Comfort Houses' ability to fulfil the occupants' needs to a house are generally satisfactory. Few problems are a result of the passive house concept, which are worth being aware of when designing future passive houses (Brunsgaard 2010c). Firstly the large windows to the south can create discomfort, because the lack of privacy to people passing by. Secondly single rooms to the north could have had more daylight and strengthen the nice view to the north. This shows that it is important to take the context of the house into account when designing, were both pros and cons of the site like looks from people passing by and the view is taken into account. The study also showed that some everyday practises of the occupants have changed after moving into the Comfort Houses. The changes that are important to emphasise are:

- Curtain and/or blinds have become a part of the everyday practice of creating privacy in some of the cases.
- The occupants needed to get an awareness of the thermal environment and therefore curtains or blinds, plus natural ventilation is a permanent part of the everyday practices in the summer period to reduce excess temperatures.
- Some occupants have become worried about the air quality and do not trust the mechanical ventilation system, but another case shows that it is possible to be very satisfied with the new system and functionality of it.
- The freedom of controlling the temperature in the houses has been restricted – a situation they just have to accept in their everyday life in these cases.

If the passive houses should become a success in Denmark it is important to be aware of the above mentioned everyday life practices in a passive house. Some of the conditions can be changes by design and information, but a solution could also be to go back to some of the technologies we are more familiar with or maybe find some compromises, so it is possible to design passive houses that fulfil the occupants' needs and allow them to have freedom and self control of the house and still fulfil the energy demands of the future. Therefore information and knowledge about both the technologies and the way to act in a passive house (or any other low energy houses) is important for this concept to be a success both for the occupant and the environment

Many of the investigated topics of indoor environment fulfil the comfort level defined for this research, but areas can be improved. Especially according to the thermal indoor environment in the summer period and the reverberation time where the occupants experience discomfort, which is both a result of "poor" design and "wrong" user behaviour (Brunsgaard 2010d). Therefore four different areas need more focus in future design and construction of passive houses/Comfort Houses in Denmark:

- Firstly it is important to define from the beginning the goals and demands of the project, to both energy performance and indoor environment, so the design team knows what to aim for.
- Secondly the design process needs to contain sufficient analysis that can predict the indoor environment of the house, which could be other and new analysis than housing designers are used to.
- Thirdly it is necessary to have a greater focus on the occupants' life and behaviour when designing, dimensioning, planning and designing the control of the systems. The user-friendliness is one way for the occupants to handle the systems correct.
- Fourthly, it is important to inform, educate and communicate to the occupant how to live in a passive house (or any other low energy house). Knowledge and communication is a source to gain trust in the concept from the occupants.
- Finally, the building concepts need to be more robust so the houses become better to handle "ignorant" and difficult occupants.

Besides the findings in each study field the comparison across study fields is interesting. And it shows that there is a high level of interconnectedness between the study fields. An interconnectedness that are greater than we are used to, because the passive house is simply another concept than conventional houses – mistakes and behaviour that goes beyond the planed will simple response much greater and either designers or occupants are used to that. This research has enlightened some of the significant areas to focus on when optimising the work with passive houses in Denmark. Hopefully the findings will find its way to the building industry and the institutions within the built environment, because the future houses have to save energy regarding EU directives and national regulations. In the process of doing so, it must not be on the expense of the indoor environment or the occupants. The recommendations will hopefully support a more holistic approach to future development of passive and low energy houses.

12 Suggestions for future work

In the light of this research project future work could continue in several directions. E.g. could it consist of both strengthening (or disproving) the existing findings and/or expand the research to cover a greater context. In the following both aspects will be outlined.

The recommendations proposed for the future production and use of passive (or other low energy houses) is mainly based on the investigation of the three study fields in focus: *Design Process*, *Architecture and Everyday Life*, and *Indoor Environment* and based on primary three case studies. The knowledge about passive houses, within those study fields, can be further strengthened by implementing more cases. At the time of writing all the Comfort Houses has been rented out and the measurement program (vbn.aau.dk/research/ (14524427) continues one and a half year more. Therefore it possible to carry out the investigations on more cases and maybe follw-up on the cases already investigated. Additionally, follow-up interviews could be a possibility if the houses one day are sold and the occupants becomes owners of the house and not tenants. The most relevant study fields would be *Architecture and Everyday Life* and *Indoor Environment*, because the *Design Process* was well documented regarding amount of cases. Furthermore, it has be too long time since the consortiums have designed the houses and they would most likely have forgotten most of the details. Further study fields could also be implemented like overall economy and compare actual energy use with calculated energy use. The latter is actually a part of the measurement project and the results will be published in the near future. It will show if the houses live up to what they promise the occupants and the surrounding society regarding the global climate and energy goals. In that connection it would also be relevant to discuss the user-behaviour versus the energy use, because it is a general perception that the user-behaviour has a major affect on the energy use.

Another approach for future work could be to test the findings on other similar cases, which would firstly produce interesting discussions about the strength of the findings and secondly compare and discuss different solutions and approaches. The analysis can also be further expanded to implement other kind of buildings like schools or offices. Analysis of other types of buildings would have different circumstances and therefore result in different recommendations. Generally, it is believed that there is a need for more evaluations of the new buildings after occupancy. Maybe the architect or engineer has some contact with the occupants after handover and get some general replies on the satisfaction of the building. Or maybe they think: no complains possibly means no problems. More systematic and scientific evaluations is desirable, because many decisions today rely on experiences from previous projects, but if they hardly are analysed, how do they know if it is the right decision?

Several times during the project this question came up: *“What about the existing building stock? Isn’t it just as relevant as new construction?”* Yes, the percentage of new constructions is very little compared to what we already have constructed but it has not been a focus in this project. There is a big potential in the existing building stock and several research project has already started to look upon refurbishment. In refurbishment we face total different problems like: the buildings already have an architectural expression and technical considerations from the time of origin. Therefore, the challenges are to combine it with the knowledge, technologies and living standards of today without losing the spirit of the original house (if desired). But it is believed that we first (or at the same time) have to learn how to design, construct and use new constructions “correct” , then most likely some of those experiences can be transferred to the existing building stock.

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Foamglas: www.foamglas.dk/

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13 Appendix

Content

Appendix A – Publications in thesis

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Articles in international journals

Publication 1: The Critical Design Process – Experiences from the first “Comfort Houses” in Denmark. Brunsgaard, C. et al. (2010b). I: Architectural and Planning Research. 16 s. (Submitted)

Publication 2: Occupant Experience of the Everyday life in some of the first Passive Houses in Denmark. Brunsgaard, C. et al. (2010c). I : Housing, Theory and Society. 25 s. (Submitted)

Publication 3: Evaluation of the Indoor Environment in the Comfort Houses - Qualitative and Quantitative Approaches. Brunsgaard, C. et al. (2010d). I: Indoor and Built Environment. 23 s. (Submitted)

Conference papers

Publication 4: Kvantitativ og kvalitativ evaluering af indeklimaet i Komfort Husene. Brunsgaard, C. et al (2010a), 3rd Nordic Passive House Conference: Towards 2020 - Sustainable Cities and Buildings. 6 s

Publication 5: Experiences from the Design Processes of the First "Comfort Houses" in Denmark. Brunsgaard, C. et al. (2009) Passivhus Norden 2009 (2rd Nordic Passive House Conference) 8 s.

Publication 6: The First "Comfort Houses" in Denmark: Experiences of different design processes. Brunsgaard, C, et al. (2009), I PLEA 2009: Architecture Energy and the Occupant's Perspective: Proceedings of the 26th International Conference on Passive and Low Energy Architecture, Québec, Canada, Université LAVAL, Québec, Canada.

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Internal reports

Publication 8: Understanding of Danish Passive Houses based on Pilot Project the Comfort Houses, in Jensen, O. B. (ed.) (2010) Design Research Epistemologies I – Research in Architectural Design. Brunsgaard, C. (2010), Aalborg: Department of Architecture, Design and Media Technology, pp. 61-78, ISSN: 1603-6204.

Publication 1

The Critical Design Process – Experiences from the first "Comfort Houses" in Denmark. Brunsgaard, C. et al. (2010b). I: Architectural and Planning Research. 16 s. (Submitted)

The Critical Design Process – Experiences from the first "Comfort Houses" in Denmark

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ABSTRACT : *The "Comfort Houses" is the most ambitious building project in passive single-family houses in Denmark until today. Eight houses are built and designed by seven different consortiums. Besides fulfilling the German passive house standard the goal was to build the houses according to Danish tradition of architecture and construction. The objective of the research presented in this paper, is to clarify the different design processes according to method and tools. The processes are evaluated according to the "Integrated Design Process" and the "Traditional Design Process" and show very different take-offs. Analysing the data we can see that: The majority of the consortiums have work with an integrated approach. But there is a tendency in all processes that the tools available are not using to document the parameters of indoor environment. This paper also discusses the implementation of the Integrated Design Process and suggests solutions to some of the barriers and thereby the future work with low energy houses.*

KEY WORDS: *Passive house, low energy, comfort, integrated design process, praxis, housing*.

Introduction

The most ambitious building project in passive houses in Denmark until today is the “Comfort Houses”. It is a 1:1 scale experiment to see if it is possible to build passive houses in a Danish context according to Danish building regulations and tradition of architecture and construction (www.komforthusene.dk). The purpose is also to find out if Danish families like to live in these houses and finally to discover which problems and barriers this approach gives in Denmark and on the Danish market. The project was initiated by Saint-Gobain Isover Scandinavia and involved building ten single-family houses as passive houses in the same neighbourhood and constructed by nine different consortiums. The consortiums consist both of architects, engineers and contractors.

The passive house standard from the Passive House Institute in Darmstadt in Germany (www.passivehaus.de) is the most acknowledged passive house standard internationally. Table 1 lists the main criteria for fulfilling the passive house standard. The passive house standard is a certification standard supported by an energy calculation tool PHPP (Passive House Planning Package), which do not take into account indoor environment or issues of sustainability. Thousands of houses have been built in Germany, Austria and Switzerland according to this standard. The passive house concept is still new in Denmark and the Danish building industry still needs more knowledge to find its own approach. Besides fulfilling the German passive house standard, the “Comfort Houses” should also have a high level of comfort – meaning daylight, acoustic, air quality and thermal comfort. The passive house solutions from Germany or Austria can not be copied directly to Denmark because of climatic conditions, the requirements to a Danish lifestyle, the traditions in the building industry and because the architectural traditions are different. Therefore it is important to find a Danish approach, to get passive houses into the Danish market.

The objectives of this research was therefore to clarify the different design processes according to method and tools to be able to use this knowledge in future projects with passive houses in Denmark. The results are based on interviews with the consortiums responsible for the design of seven of the houses.

The project of the “Comfort Houses” was planed as a competition to select the ten houses and consortiums. The design proposal should be a concept that most likely would be able to fulfil the passive house standard. They had to document an estimated energy demand and cost of the building. After the selection of the winners, they received a fixed budget, which was determined on the basis of the expected market value of the house plus an extra sum to cover the expected extra cost of constructing a passive house. The initiators did not dictate a methodical approach of the project, but they asked the consortiums to work in a cross-disciplinary manner through teamwork. Figure 1 show the eight those “Comfort Houses” that was certified as passive houses.

Table 1: The table shows the demand of fulfilling the passive house standard (www.passiv.de)

Space heat demand:	Maximum 15 kWh/year per m^2 net area
Primary energy demand:	Maximum 120 kWh/year per m^2 net area (incl. household)
Infiltration:	Air change at maximum 0,60 h^{-1} with a pressure difference of 50 Pa

Figure 1: Overview of the Comfort Houses that fulfils the German passive house standard.

Other research about design processes

Much research about design processes are based on case studies. Mureen Trebilcock has made studies of the design processes behind eight sustainable buildings in Europe and South America (Trebilcock 2009). She explains (based on work by Hillier, Musgrove and O´Sullivan) that there are researchers who believe the model of integrating environment sustainability in architecture is based on an understanding of the design process as Analysis/Synthesis (A/S); where the problem is broken down and analysed in sub-problems and individual problems, after that reaching individual solutions and sub-solutions until achieving the overall solution. She proposes that the Integrated Design Process (IDP) in practice is closer to a Conjecture/Analysis (C/A) model that suggests that designers would propose an idea that is *holistic in nature* before attempting to do any analysis. These terms describes the difference between research and practice and also the difference between the architectural (C/A) and engineering (A/S) approach and explain the conflict in combining these two paradigms in an IDP like the one developed by IEA Task 23 (Löhnert 2003). She concludes among others that it is necessary to have a C/A perspective to IDP, because she thinks it is *"…unlikely that integration could be achieved by analysing enormous amount of information, synthesising and evaluating it until finding the optimal solution, …".* And conclude that the education of architects and engineers has to cover a basic knowledge and skill of the other profession (Trebilcock 2009).

James W. Axley has similar statements. He describes through two case studies of innovative practices, that leading environmental engineering firms have outpaced the technical research community, because this community has focused too much on the development of checklists and/or fixed-idealization computational tools, which according to Trebilcock´s findings belong to the A/S model. The engineering firms has focused on more fundamental theoretical development and prepared design engineers for innovative practise instead of the conventional. He also states that a design process is cognitive and therefore very difficult to use prescriptive approaches like guidelines in praxis – they actually limit and burden the design process (Axley 2004).

The research in the Ph.D. thesis by Hanne Tine Ring Hansen also touches upon design processes. She has interviewed two designers who have experience with IDP in practice (Hansen 2007). She makes similar conclusions as the above but with a little different terminology. There are professional differences between architects and engineers; the engineer has a problem-focused strategy and the architect has a solution-focused strategy for problem solving.

The consortiums in the Comfort Houses have as mentioned not been introduced to any theories or methods about either IDP, A/S or C/A approaches before designing the houses. How the different processes have unfolded in connection to passive houses is interesting in the way to understand the practise today and how we should design in the future.

Theories about design processes

The knowledge from the interviews about the practical experience is compared with approaches of Integrated Design Process (IDP) and the "Traditional Design Process" (TDP) to illustrate what kind of processes the consortiums have had when designing Comfort Houses. In the following different theories about design process are presented.

General introduction to design processes

Design processes are not easy to define, because the design problems are often ill-defined and wicked. No design problem will ever be the same; therefore each design situation is unique. Additionally, they often have great complexity e.g.:

“Enlarging our windows may well let in more light and give a better view but this will also result in more heat loss and may create greater problems of privacy. It is the very interconnectedness of all these factors which is the essence of design problems, rather than the isolated factors themselves.” (Lawson 2002, p. 58-59)

This complexity affects how to approach the design process. Many writers have tried to map the design process in identifiable activities in a logical order, but those attempts turn out to be rather rushed. Lawson suggest instead a “map” of a design process, though without a beginning or end, which illustrate how design processes often have very little direction, because all issues inform each other, see Figure 2. The designer need to go back several times to identify another problem and establish another solution and visa versa (Lawson 2002). This is what Donald Schön would call “reflection-in-action” or “having a conversation with the drawing”. He talks about a spiral process which leads from *understanding* to *action* (attempting a solution) and to *new understandings*. The designer understands the unique and uncertain situation through the attempt to change it, while at the same time change it, to be able to understand it (Schön 1983).

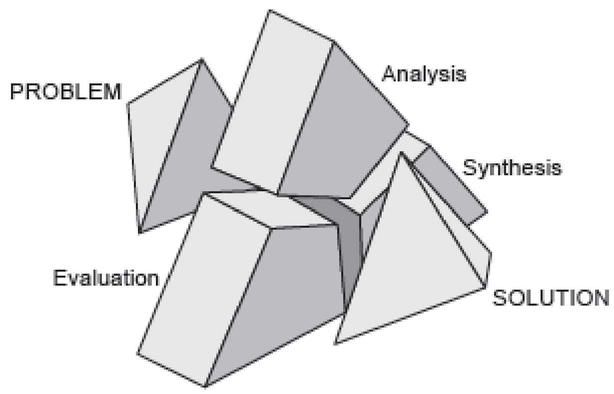


Figure 2:Bryan Lawson´s map of the design process: “The design process seen as a negotiation between problem and solution through the tree activities of analysis, synthesis and evaluation” (Lawson 2002, p. 47).

Theoretically there are several solutions possible, but only one of these will be the final solution and reductions have to take place. Hillier, Musgrove and O´Sullivan reject an Analysis/Synthesis approach and agues for conjecture in design development:

“We have to recognise, therefore, that before the problem is further specified by the gathering of data about the problem, it is already powerfully constructed by two sets of limiting factors: the external constrains(…) and the designer’s cognitive capability in the relation to that type of problem. It is quite likely that these latent limitations are already being explored right from the beginning, if the designer is conjecturing possible solutions, or at least approximations of solutions, in order to structure his understanding of the problem, and to test out its resistances. There is also a very practical reason why conjecture of approximate solutions should come early on. This is the vast variety of design decisions cannot be taken – particularly those which involve other contributors – before the solution in principal is known.” (Hillier et al 1972 p. 29-3-9).

The design process is a cognitive process and the designer conjecture an approximately solution to structure the understanding of the problem and tested its resistance. They therefore state that design proceed by conjecture-analysis (C/A) rather than analysis-synthesis (A/S) (Hillier et al 1972), the understanding which Maureen Trebilcock also used in her research.

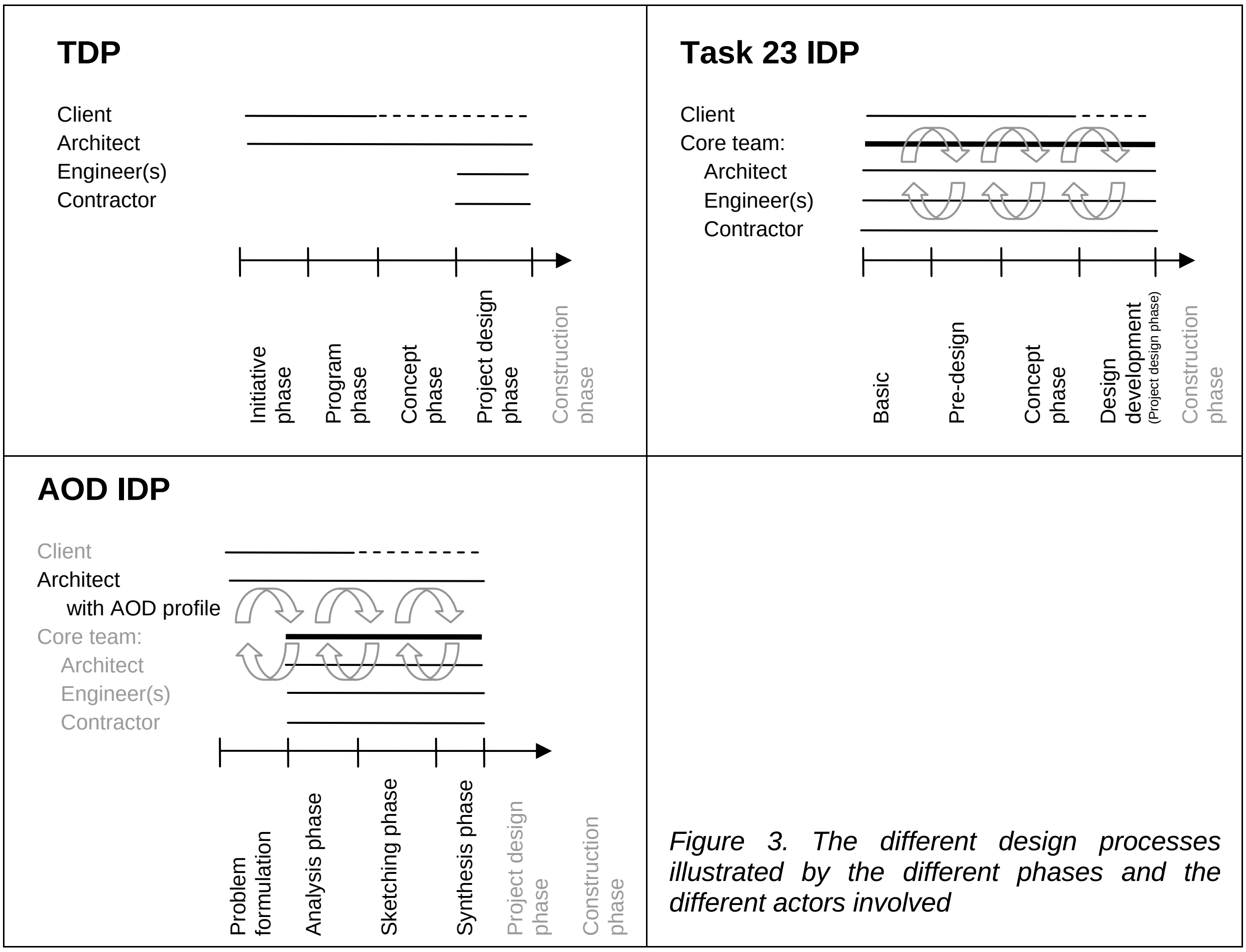


Figure 3. The different design processes illustrated by the different phases and the different actors involved

Figure 4. The conceptual diagrams show how the process develops according to the level of integration of the architectural and technical aspects in the different design methods (Developed on the basis of the primary literature).

The design processes in practise which could be called the traditional design process (TDP), if generalised, often proceeds like this: The architect and the client agree on the design concept consisting of the form concept, orientation, fenestration and the exterior appearance like characteristics and materials. Then the engineers and consultants are asked to implement or design technical systems for the building. This procedure is quite simple mainly because the "active" actors in the process at the same time are limited and they are implemented linearly (Muir et al 1995 and Löhnert 2003), see also Figure 3 (TDP). In a linear process it is often difficult or even impossible to optimize the design according to e.g. energy and indoor environment, because the expertise comes in late in the process. This is a problem especially when designing low energy houses where even more parameters are important to consider than in standard building design fulfilling the conventional level of performance (Löhnert 2003). As described above the architect has a more cognitive approach and highly use reflection-in-action and switch between problem and solution, where the engineer more is a "problem-solver" that has a scientific and analytical approach to find solutions, which Figure 5 illustrates. Therefore it is stated that TDP have the "layout" illustrated in figure 3 because the different professions have different ways of approaching the design and "split the process between them".

The design processes have become even more complex today because the goal to make low energy also affect the architectural design of the building – today the goals cannot be reached just by technology. The resulting energy use and indoor environment is highly depended on the building envelope and planning of the rooms. Therefore the architect either needs more knowledge or need to bring in expertise on another design stage than they are used to, to reach the goals. To deal with higher level of complexity some suggest the IDP approach.

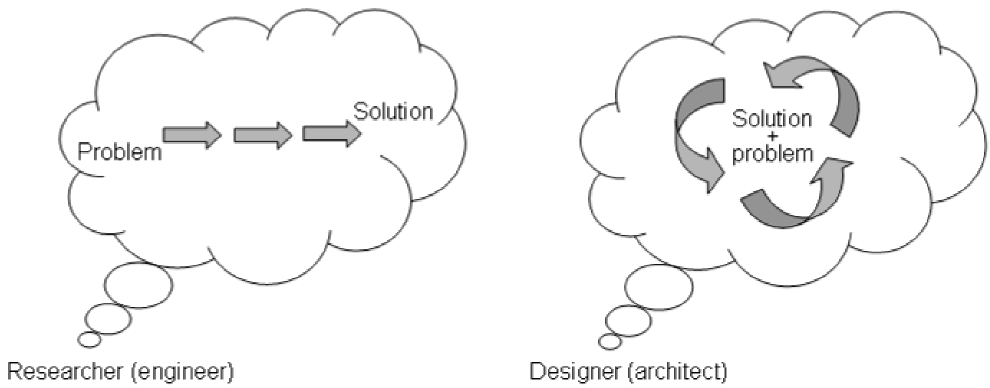


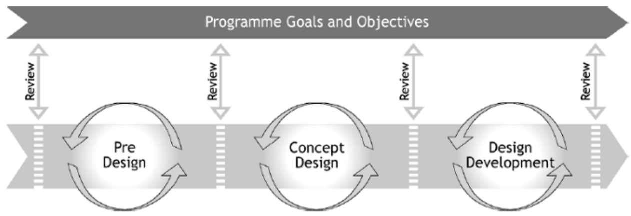
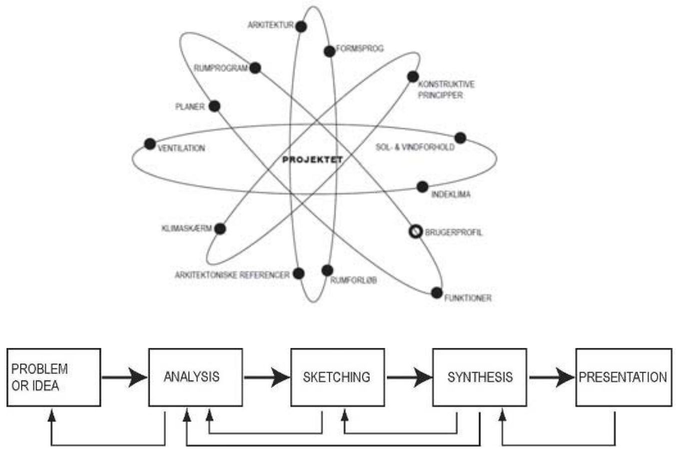
Figure 5: The diagram show the difference between "design" thinking of a researcher and a designer. The researcher has the analytical approach to find a solutions, where the designer sees the problem and solution as interdependent - the problem is revised and specified in relation to the results of "experiments". (Developed on the basis of the writing of Donald Schön, 1983)

Different integrated design process (IDP):

In the last years a number of different approaches to IDP have been developed and some with a slightly different naming like: Integrative Design Guide to green building by Bill Reed (Reed 2009) Integrated Energy Design by Esbensens Consulting Engineers (www.esbensen.dk). Generally most of them wish to fulfil the same goal but have different visions and aims. They generally focus on the importance of integration of both engineering and architectural design aspects in a holistic synthesis, but they still vary when taking a closer look. The selected focus parameters in the method, steps and milestones and the implementation of actors and their position in the design process vary. The outline of the method often depends on the developer's main professional interest. Most approaches to IDP include an iterative process, where all design aspects are discussed by all actors in the team – like method from IEA Task 23 (Löhnert 2003) or the Integrated Design process developed and used at Aalborg University in the education Architecture & Design (Knudstrup 2004, Knudstrup 2007), which will be the IDP approaches referd to in this work. Figure 3 and Table 2 explain and compare these two IDP approaches according to TDP. To further illustrate the different content and focuses of the methods conceptual diagrams are developed. They illustrates how the development of the processes regarding integration of both technical and architectural aspects proceeds, see Figure 4. *Technical* means in this case energy and indoor environmental issues. The diagrams show that the IDP approaches vary according to the TDP. Trebilcock states that the Task 23 IDP is an adjusted model that tries to combine the two competing visions of A/S paradigm and the C/A paradigm (Trebilcock 2009). This work in some way agrees, but on the other hand it depends on the interpretation of the description of the work. In what paradigm the AOD IDP fits within is not obvious at first. The design approach is developed from an architectural point of view which according to Hiller et al. would be a C/A model. But the content of the analysis phase covers among others analysis of site, urban development plans, materials, chart of functions, principles of energy use, indoor environment and construction etc. which end up in aim and programme and the first idea's to the building concept. How these analyses are performed can define whether it is an A/S or a C/A model. It is believed that the AOD IDP has a more C/A approach as the candidates is trained to get a general understanding of technical aspect in an architectural context. Therefore the conjecture will through the obtained experience during the education become more and more *holistic in its nature*.

Table 2: Examples of different Integrated Design Processes

<table>
<tr><td>International Energy Agency (IEA) Task 23 (Task 23 IDP):

Optimization of Solar Energy Use in Large Buildings, subtask B (Task 23 IDP). In this approach the client takes a more active role than usual, the architect is a team leader instead of a sole form-giver and the different engineers, including an energy specialist, takes an active part in the early stages of the process. The process is based on specialist knowledge of each actor. The design develops through iterative operations (Löhnert 2003).</td><td>
</td></tr>
<tr><td>The Integrated Design Process, Architecture & Design, Aalborg University (AOD IDP).
This approach is developed as a method for architecture students at Aalborg University and is developed from an architectural point of view. The work is based on the architects design process but includes consideration of some basic technical engineering parameters and application of tools from engineering in the beginning of the design process. All persons carry a new professional interdisciplinary profile that aims at integrating architectural skills and the necessary engineering skills and tools to fulfil the goals. The design develops through iterative operations (Knudstrup 2004, Knudstrup 2007).</td><td>
</td></tr>
</table>

Method

The researches of the design processes behind the "Comfort Houses" are analysed trough qualitative focus group interviews of each consortium. A focus group interview in this study is an interview with more interviewees, which are the actors in the consortium or at least some of the actors in the consortium (Bryman, 2004). The interviews are carried out as a semi structured interview, which means the interviewer has a question guide with a series of questions that are in a general form. The interviewer is then able to vary the sequence of questions and further questions can be asked to what can seam significant for the research (Kvale 2007). A focus group interview is carried out as a conversation among the interviewees and the interviewer. Each interview is analysed individually and summarized in a report, which is published together with the question guide in "Interview Report about the Design Processes behind the ´Comfort Houses´" (Brunsgaard 2009a). Finally the interviews are analysed in a comparative study.

The advantages of focus group interviews instead of one-to-one interviews, are first of all that the interviewees are able to probe each others point of view, which can make people think of something they in a one-to-one interview would not have thought of and people are able to modify or qualify their view, which can bring wider views to the investigated topic. The fact that the interviewees argue with each other and challenge each other can result in more realistic opinions, because they are forced to think about their views and maybe revise them (Bryman, 2004). The weakness with qualitative focus group interviews are e.g. some participant might hold back their own opinion, because they are conflict-averse or in this case the consortium think of their company's reputation and want to give a good impression of their firm. Other things the interviewer has to be aware of when using the qualitative interview are e.g. the lack of transparency in the investigation. It can be difficult to see what the researcher actually did and how he/she got to the conclusions. The reader is dependent on the researcher's selection of statement and the context they are placed in. Another thing is the understanding of what is being said both during the interview situation and later in the transcribed interview. It can be essential what the interviewer thinks the interviewee means by a certain phrase or term. Therefore it is important to validate during the interview by summing up what has been said or ask about the meaning for the interviewees to confirm or clarify. Other ways of controlling the analysis is to use more researchers in the analysis of the same interview. It can lead to richer analysis and clarification of terms. Another solution is to present examples of the material and careful account for every step in the analysis process (Bryman, 2004, Kvale 2007).

Results

The results are presented in two sections. First the different design approaches is discussed and identified and later the tools applied in the design processes are presented. The results are presented by conceptual diagrams and quotes from the interview. Further details about each interview can be found in the report ”Interview Report about the Design Processes behind the ´Comfort Houses´” in Danish (Brunsgaard 2009a).

Identification of the different design approaches

As mentioned earlier the consortiums were not told to use a certain method in the design process and the interviews also showed that all consortiums have worked without a specific method or at least they have not been aware of it other than some have based the designs on strategies like e.g.:

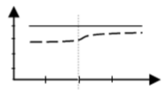
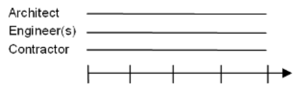
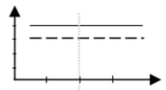
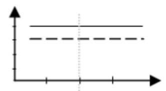
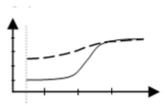
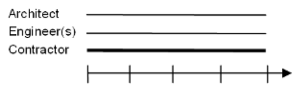
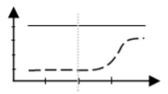
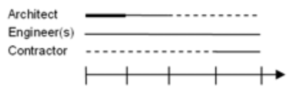
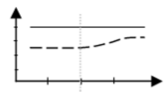
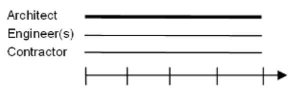
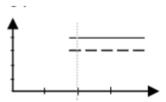
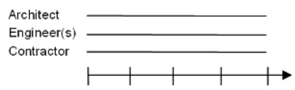
- “Make it simple” as a main guideline for the whole project.
- Outlining a number of focus parameters – some both covering technical and architectural aspects
- ”Trias Energetica” principle, that focus on the energy design (www.triasenergetica.com)
- Performing “analysis of consequences” of different design solutions.
- Or simply designed solutions “on the safe side”.

These strategies are more or less integrated regarding the different definitions of IDP. To illustrate the different consortiums approaches to the process individually and compared to each other, their approach are placed in a matrix in Table 3. The design approaches are illustrated in conceptual diagrams in the same way as done with IDP approaches in Figure 4. Additionally the matrix shows the level of experience the consortium have had before the project and a diagram showing when the different actors have been involved in the process. The matrix shows variations in the different approaches and that the majority of the consortiums have worked very different from the TDP and similar to the IDP, even though they were not introduced to any IDP method. The reason for that might be that the initiators of the project asked the participants to create a consortium, work in teams and share knowledge, even across consortiums. The teamwork-approach can have made some consortiums approach the process more integrated than usual. Maybe they also felt the need to discuss the different design issues with each other because it is a pilot project and the concept of passive houses is new to them. A comparison shows that there is a tendency that the consortiums with the most experience also are the consortiums with the most integrated design process. This might illustrate that the experienced consortiums have found out that they need an integrated approach (without defining it as such) in this type of projects and therefore took this approach. An example of the integrated approach is well illustrated in this quote by consortium 3:

”We did not think architecture and then think technique which should be stuffed into the architecture afterwards. Or architecture first and then we had to document if the energy calculation is fulfilled afterwards. We made some sketches and calculated, considered the technique, then we made changes, considered the technique again, calculated energy - and also considered how we practically should build (the house) … We continuously did that in steps, where we tried to keep all the things (parameters) in focus at the same time, instead of trying to fix it or bring it in at a time where it is hard to get it integrated.” (The engineer, consortium 3)

If the technical aspects have been integrated well enough in all the processes can be discussed, but generally all consortiums have had a C/A approach. None of the consortiums have made profound analysis of different energy or indoor environmental aspect, which would characterise the A/C model. Most consortiums develop, together as a team, an idea that is holistic in nature before doing any profound analysis.

Table 3: The matrix shows a quantification of some of the result of the interview.

	Previous experience with low energy buildings (Much, some, limited)	**Design approach** —— Architectural aspects – – – Technical aspects ······· Competition deadline	**Phases and the actors involved**
C1	Limited		
C2	Much		
C3	Some		
C4	Limited		
C5	Limited		
C6	Much (Architect with interdisciplinary profile)		
C7	Much		

The processes have of course not been without problems including the most integrated processes. Consortium 2, which have had a very integrated process, has experienced that the boundaries between the professions are more unclear than in a TDP. Even if all actors are present in the discussion and all agree on a decision, it might not be clear who is doing what and when. In consortium 3 they have experienced that even if they have agreed on a certain design aspect, it later turns out that they had different understanding of the same decision because of their different professional traditions e.g. they could agree that at certain solution should be *fancy.* The architect had one idea of fancy, the engineer a second one and the contractor a third idea. This shows the very importance of dialog and openness to understand each others set of mind when working together in the design process. In consortium 1 the team is so focused on the “new” technical engineering aspects that the architect nearly forgets to focus on the architectural qualities of the house. When the architect was asked about which architectural qualities have been important in the design, the answer was that they were closely connected to the energy goals. But during the answer the architect became aware that the energy goals had nothing to do with architectural qualities and says: *“I do not know what architectural qualities there are in that (answer). I guess it is more some kind of program parameter.”(The architect, consortium 1).* A reason could be that the architect might have been hypnotized by the quantitative goals and did not manage also to think of the architecture at the same time. New things take time to learn how to take into account and because the project is a learning process, the new aspect might have taken up more time and attention away from the architecture. But on the other hand it also shows that the architect is being open to new insights from other specialisations – a knowledge that hopefully would be “stored” for future projects.

Especially two cases do not fall into the integrated approaches. In consortium 4 the project had such binding constrains that the architect was not able, in her own opinion, to design good architecture within these, it resulted in architecture, but not as good as it could be:

“Of course you would wish that there had been constructed something … a piece of architecture, right? But because it should express something that both is typical to a Danish standard house, at the same time something that the contractor could bring out to the market and at the same time be the

cheapest, then it had a lot of constrains in relation to the architecture … The technical part is the "heaviest" (part) in a single-family house in one storey. I think so as an architect. It means that you do not sit down and sketch by a loose hand. You draw a rectangle and send it to the engineer and ask: ´Is it better now? ´ There is no architecture in that, in principal. ´Should it be a little lower? Arh 20 cm lower ceiling inside´ … It has been a challenge according to think architecture and at the same time think of a passive house in one storey … "(The architect, consortium 4).

The architect thinks the design process was different because the priorities was different than in a "traditional" process. They describe it like this; first they thought of the teamwork, then the goals and demands of the project and finally the architecture. Both the architect and the engineer had limited experience with low energy housing therefore they both felt unsecure when approaching the project. The architect could not sketch "by a loos hand" and the engineer was not familiar with the calculation tool which is used when designing passive houses. What the architect calls "sketch by a loos hand" is interpreted to be what Donald Shön would call "reflection-in-action" (Schön 1983). The knowledge and experience which is necessary to reflec-in-action was simply not present, therefore they felt the process was very fragmented. This is believed to be further strengthened by the fact that the companies physically was located far away from each other and resources was used on the common workshops in the overall project and not on specific design meetings in the consortium. To carry out a successfully IDP based on those circumstances seems difficult.

The process in case 5 had a little different characteristic. They explained that they had a different approach and teamwork than they were used to in a more traditional project – they had much closer collaboration from the beginning of the project. They further explained that the design was developed by the architect and the engineer and the contractor was placed on the side in a "position of listening". He could use a red or green flag if the economy was fine or not. His role was not really integrated before the actual calculations on the economy had to be made. As the interview moves ahead the notion of close collaboration might not be so close after all. One engineer explains the process like this:

"We knew it should be a passive house, but he (the architect) was not so constrained by it in his first creative process because he was thinking of how he could design a super attractive building aimed for the modern family. And then we tried (the engineers) to drag it back and said: what should be done so it could become a low energy building? He was given free rein, free enough that he could try to make some first sketches. ... Of course we had given the architect basic knowledge by saying: 40% of the window area should we try to orientate to the south." (The engineer 1, consortium 5)

This design approach seems similar to a TDP, because the architect developed the architectural concept and later the expertise of the engineers come in and they "drag the design proposal back" as they say. Another engineer in the consortium supports this in a later section in the interview:

"I think is was a bit annoying that you in principal sketch a house, and there was not a long time available to do that, and win the competition, wupti! Then you have promised how it should look like, what building services it has and … the cost. Then you are extremely constrained, right? And that is before you have had the time to consider the design, because you have not had the time to calculate and you actually do not know very much (about passive houses). … What was it that we were about to do? We had to learn, but we could not use that for anything because we had promised (how it should look like) … we could have changed a little on the windows ... But we had promised how the house should look like and it is really the architectural idea how the window is placed ... then you cannot change that." (The engineer 2, consortium 5)

This engineer felt that she had too little influence on the architectural concept and her knowledge and expertise could not be implemented. This could be categorised as a C/A approach but the conjecture in this case was too weak, the first suggestion was not *holistic* enough *in it nature*, which made it difficult to fulfil the demands of passive houses according to the quotes above. This tells something about the communication and the teamwork in the consortium. If the engineer had been a more integrated part of the first ideas, the concept might have been more holistic.

The process of consortium 4 and 5 show how intensions of working close together in an integrated process can end up being very little integrated, some actors ended up being even frustrated about the process. It does not mean that the outcome of these processes is poor, but it says something about the path to the final result. By optimizing the process maybe the consortium could have saved resources – both personal and economical resources.

The consortiums were asked to mention some recommendations to others that wanted to design passive houses. And they pointed out the following:

- It is important to have a good teamwork early in the design process and work cross-disciplinary
- The teams have to see the design task as a joint mission and all aspects concern everybody
- All have to be enthusiastic about the project and the partners have to trust each other
- The energy aspects have to be integrated into the architectural expression from the beginning of the design process to achieve good solutions
- Draw up some guidelines that should be followed in the design process e.g. define focus parameters

Putting the recommendations together, they fit into the concept of IDP – the approaches of Task 23 IDP and AOD IDP. Additionally they fit well with the recommendations by Tom Muir and Brian Rance in what they call *collaborative teamwork* (Muir, T. et al 1995, page 19-20). The recommendations illustrates that the consortiums indirectly think that it is necessary to work more integrated in the future. Even so, the architects in consortium 2 and 3 suggest that it might just be in a period we need to work in an integrated way - until the architect have got a better and general understanding of the “new” aspect of building design. But the question is if the architect should go back to be the sole form-giver? And the engineers be the problem-solvers? One of the architects changes his opinion after discussing with him self. He thinks it is better the architect do what they do best – design good architecture and then work together with the specialist from an early stage. He thinks it will bring us much further with the design. Therefore is it stated that even if the architect through time could get more experience and roughly estimate most of the characteristics of a passive house, it is still recommended to work cross-disciplinary from an early stage. This way it is possible to recommend substantial changes before it is too late or very expensive to implement. No dough that as the actors get more and more experience they will be better to make preliminary concept that are more holistic in nature (C/A-model).

Tools applied for documentation and design development

In an IDP it is essential to use tools to document if the requirements are fulfilled but also to ensure that the design is moving in the right direction during the process. The understanding of tools in this project is divided into three categories: Architectural, energy calculation and indoor environmental tools. The typical tools the consortiums have used are shown in table 4. In typical building projects the same architectural tools and the energy documentation program Be06 are used. The main difference in this project was that the houses also had to be certified as passive houses and therefore the energy use had to be documented by PHPP, which was a new tool for most consortiums. The PHPP tool has been used continuously through the detailing phase. There were two tendencies in what way PHPP has been used:

- A design proposal was made and afterwards calculated if it fulfils the requirements, if not, redo the design and calculate again – “Trial and error”
- A reference building was designed and calculated. Then different changes was made and calculated. The changes and the consequences on the energy use was listed and then discuss what direction to go with the design – “Analysis of consequences”

The latter has been a success for the consortium using this approach and especially a success for the architect, because he got a common understanding of which design decisions had influence on the energy performance and how much. He exemplifies like this:

“…all those aspects are put up in the schema and what it actually means when we reduce the window area with 7%. It means this and this in the big score… What will it actually mean if we turn … up here or down there? Both on insulation, on values of the window, on argon/krypton, all things like that. It was something the engineer had in his head and suddenly it came out to the rest of us. And that was fantastic because it was some of these things that actually made it possible for us (architects) to understand … (what) was necessary to be able to fulfil the numbers which it was all about. In other word, we had a feeling of what was happening … We have used that (later) as an example of how we would like the engineer to work in the future with some of the things we do not known about." (The architect in consortium 3)

Table 4: Typical tools the consortiums have used during the design process.

Architectural tool	**Energy calculation tools**	**Indoor environmental tools**
– AutoCAD – Hand sketches – Some 3D modelling in the sketching phase	– Be06 in the early stages of the sketching phase (Danish software for energy calculations) – PHPP in the detailing part or in the whole process (Passive House Planning Package (www.passivehaus.de))	– Static calculations of the risk of overheating in PHPP. – Other indoor parameters as daylight and noise are not documented by calculations. The solutions are instead chosen according to the experiences from other building.

This consortium also tried to extend the analysis with an economical parameter, which also made the contractor more active in the earlier phases. This approach could be defined as *the technicians were making sketchy calculations* or *they were sketching with their calculations*. It is believed that this approach shows a good communication in the team, they are openminded and have an interest in understanding other specialities. The first approach "Trial and error" is instead split up in specialities knowledge, one designs and one calculates and is more categories as a *hypothesis-testing* approach. It can also be successful to use this approach, but the communication between professions becomes an even more important factor in the teamwork to be able to understand the progress of the design and not using too many resources on testing in various directions.

According to documentation and analysis of the indoor environment, the tools the consortiums have used have been very limited. In most consortiums the thermal comfort according to overheating was calculated in PHPP, while indoor environmental aspects like daylight and acoustics in the majority of the cases were only discussed. The design solutions were then based on well known solutions or based on solutions that might accommodate a well known problem. Most consortiums know the tools, but they are not used to work with them especially not in single-family house designs. By not using the tools problems might arise as solutions selected are based on existing building cases. The existing building stock is constructed very differently than the "Comfort Houses" and therefore the consortiums can not be sure if it will react the same way. E.g. the walls are much thicker than in a standard house and can result in less daylight in the rooms and the orientation of the house and windows are much more fixed. Furthermore many existing buildings have poor indoor environments and the right solution to the problem could be several. E.g. many complain about acoustics, more specific the reverberation time. If the solutions chosen for the "Comfort Houses" are not documented and existing examples are poor, how do they know if they fulfil the comfort requirements? When asking the consortium about what comfort is in their opinion, they gave an equivocal answer. Some thought of technical aspects like daylight, noise, air quality and thermal comfort, but most consortiums also mention architectural qualities like spatial experience, connection to outdoor areas, materials etc. Additionally some consortiums mention practical aspects like easy to clean, easy to live in the house and enjoying the house. This shows that comfort is not a well defined aspect in the design process – it covers both quantitative and qualitative aspects. Most consortiums did not mention all the technical aspect, so maybe that is also a reason why they did not document all aspects of the indoor environment. Maybe they are simply not aware of what the term comfort covers technically or maybe they have forgotten them in the design process because of the large focus on energy use. Another reason could be the initiators. They did mention requirements for the indoor environment in the tender documents, but they did not write defined criteria so the consortiums knew what to aim for. It is understandable that the more qualitative understanding of the term comfort is varying, but it is a shame that the quantitative aspect of indoor environment is not more embodied into the design processes. Today we spent most of our time inside, especially in Denmark; we should have much more focus on the indoor environment. People have to live in the houses for more than 50 years. Why not do it properly the first time and use the tools available? Another paper will document the resulting indoor environment in the "Comfort Houses", both according to temperature, CO_2, humidity, daylight, noise from installations and reverberation time. The data will be compared with the residents experiences of the indoor environment based on qualitative interviews. [http://vbn.aau.dk/research/(14524427)/]. The preliminary result of that report is presented in a paper from the 3rd Nordic Passive house conference (Brunsgaard 2010).

Implementation of IDP

All consortiums state that the future design approach should be something different from the TDP. The result of the analysis seems to aim for a methodical approach in the IDP region of Task 23 IDP and AOD IDP, because all consortiums agree that all actors has to work together from the beginning of the design process and the design is a joint mission. Furthermore, the majority of the cases have approached the assignment with a more integrated approach than the TDP. The method of Task 23 IDP, is suitable because it is based on the actors' individual professional knowledge (they do not carry a interdisciplinary profile) and can be introduced in the existing practises today. Maybe not in its pure form, but adjusted to the individual project. The projects in the "Comfort Houses" had a C/A approach where the architect and engineer (and contractor) together developed a holistic design proposal which then is optimised and tested by tools, mostly PHPP in this case. This indicates that extensive analysis of e.g. low energy components is not necessary, as Task 23 to some extend describe.

The problems we face in the IDP based on this study are mainly within the communication and understanding of each others professions and the knowledge when and how to document the design. A clear solution to how those problems should be solved might not exists, but maybe it is a matter of getting more experience with closer collaborations and getting a better understanding of each other's professions. Another solution, which could support that, could be to include a Design Facilitator (DF) which has the interdisciplinary competences. Task 23 IDP suggest the use of a DF in the definition of the method. The role of the DF can vary, but generally the main idea for him/her is to manage the design process. Based on this study a DF should have a broad knowledge and understanding of the language of both architecture and engineering. A DF should have the overall view of the project and thereby discover unclear issues, which for example could be missing documentation of the indoor environment as seen in this study. To succeed it depends a lot on the DF´s qualifications in both architectural and technical aspects. He/she has to have a general understanding of both fields but still sufficiently deep to discover problems or unclear issues for the team members to be able to solve them. But the question is what kind of profession could fill out the role of a DF. It is believed that it is easier for the architect to pick up knowledge from the engineering than the other way. The argumentation for that is because the engineering field is based on quantitative knowledge which is measurable and well defined and the architectural field is qualitative and based on more subjective point of view – kind of apprenticeship which cannot be taught by reading a book. The aesthetics and artistic field of architecture takes years of training to understand, but to get a general understanding of the consequences of the design changes on the resulting energy use is easier because it is easier to discuss and define. Therefore the first suggestion for a DF would be an architect, who has several years of experience with passive or low energy houses and has a big interest in the technical aspect of energy and indoor environment – A regular architect would not be able to get the full overview of all aspects in the process. A problem, especially in Denmark, is that only few actors in the building industry have experience with passive houses or low energy buildings that could give them sufficiently knowledge. Therefore another suggestion would be to use an architect trained in using AOD IDP as DF, because they know the different approaches and the tools and can understand the architectural as well as the engineering language (Knudstrup 2006).

Another thing that could strengthen the IDP besides a DF is change in education of both engineers and architects. Today most of them are educated to work within the TDP. E.g. the engineers learn to be problem solvers, meaning they have to fit the technical aspect into an almost finish architectural design. If they instead learned during their education to be more creative and see possibilities in different design solutions their education fits better to IDP. They should be sketchier with their first ideas like architects do with their first drawings – they should be introduced to use a more C/A approach. Then as the design process develops the solutions is getting refined. On the other hand is the education of architects too independent of the technical aspect. Especially the traditional education of Danish architects, they mostly work with an intuitive artistic approach. No doubt that the Danish traditionally educated architects design very good aesthetic buildings and it is important we do not loose that, but it is important they also are introduced to technical aspect and learn that they are not going to be the sole form-giver in praxis. That way the future designers, both architects and engineers can be prepared to changes in the design processes in praxis. Trebilcock do not suggest the use of a DF, but she also suggests that the architect and the engineer overlap their knowledge and skills in future design processes and that they use a C/A model.

But how is the knowledge of the IDP methods in praxis today? This study shows that it is definitely not sufficient; none of the consortiums have used or pointed out any defined methods. Why is the building industry not more familiar with IDP methods? This study can not give the answers, but there are definitely some barriers for the method to work in praxis. The research of H.T.R. Hansen states that the barrier of integrating IDP in praxis is the fact that the architects protect their professional domain and the engineers do not want to intrude on the architectural domain. Another barrier is that the professions are not trained to work in an integrated way. Besides that the building industry is not based on trust and openness to each other, which is important in an IDP. Additionally there are some problems by creating a consortium from an early design stage, because of the compulsory competitive tendering for the public sector. And finally there are very different definitions of the IDP, which this article also shows in the theoretical section about design processes. That might be the first place to start. Which of these methods work the best, if it is possible to answer that? Maybe it varies form project to project which one is the most suitable. It is believed that in most projects the IDP in the region of Task 23 IDP and AOD IDP will no doubt be a good alternative to the TDP.

Conclusion

The study of the “Comfort Houses” has shown the width of how a design process of passive houses can be approached. But it has also showed that the IDP approach is beneficial, it respect all part of the building design aesthetic and technical. To make it work the circumstances need to there. This study has showed the importance of:

- actors adapt expectations and agree about the goals and aim,
- establishment of interest in each others field of specialisation,
- and including the different expertise in the design process from the beginning.

It is believed that we are on the way towards more integrated approaches, but there are still barriers, which to some extend is far from being broken down. The institutions are still educating specialised candidates and thereby missing the general understanding of different way of *reflection-in-action*. Therefore architects and engineers do not want to intrude on each others domain. But the increased level of complexity in passive houses and low energy houses, which also affect the architectural expression, needs other expertise earlier in the process than “traditional” housing. The actors in the building industry simply need to gain trust in each other.

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Autobiographical sketch

The main author got a master in civil engineering in architecture at Aalborg University in 2007. In the final three semesters of the master the author has focused on designing low energy houses, because she finds the field very challenging and interesting. She also believes we need to move toward low energy buildings in the future designs of our buildings. Immediately after finishing the master degree she started on a Ph.D. thesis about comfort houses (passive houses), which this article is a part of.

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Publication 2

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Occupant Experience of the Everyday life in some of the first Passive Houses in Denmark

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Abstract: *In the future years, the building industry is facing great challenges in fulfilling the stricter energy demands. One way to meet the requirements is to build passive houses. Especially in Germany they have constructed passive houses for many years but in Denmark the building industry has just begun. The pilot project named the Comfort Houses wants to show the industry that it is possible to construct traditional Danish houses as passive houses and promote them as comfortable houses. In order to make this become a success in the future, it is necessary to fulfil the occupants' needs and wishes. This study wants to communicate how the occupants of the Comfort Houses experience living in a passive house and illustrate if their lives and everyday practices have changed after moving in. This is done through interviews with the occupants about their everyday life both in their previous home and in the Comfort House. The results show that the occupants' everyday lives have changed – some are a result of the architectural and structural solutions, others are a result of the technology integrated in the houses.*

Keywords: *Passive houses, everyday life, interviews, architecture, indoor environment, comfort*

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Introduction

Today and in the future, the building industry faces extensive challenges in fulfilling the stricter regulations regarding the energy performance of our built environment (Directive 2002). A simple and effective way to reach the energy performance in new buildings is to build very energy efficient houses like e.g. passive houses according to the passive house standard defined by the Passive House Institute in Darmstadt, Germany (www.passiv.de). When constructing low energy houses or passive houses the design team faces new challenges regarding the shaping and planning, the building technology, the technical service systems etc. These changes are more than just physical changes, they also affect the lives of people living in the houses. This paper presents the work of a research project where the everyday lives of three families in some of the first Danish passive houses are investigated. It will show if the occupants have undergone changes in their everyday life and if it is something they are comfortable living with or not

The construction of passive and low energy housing has already begun in the building industry but for it to become a large success the author thinks it is necessary to create buildings or homes that are complete and holistic solutions. Previous examples of low energy buildings have been represented by more alternative and odd-looking buildings, e.g. Villa Vision and Friland, figures 1 and 2, where certain behaviour and/or technology is required. In order to become a success, it is believed that the future low energy houses should be something recognizable and attractive and maybe not so different from what the Danish population is used to. This means that functional and qualitative requirements also need to be integrated in the design solutions instead of just meeting the energy goals of the future. The buildings or homes need to be designed in a way that the occupants can relate to them and live their lives comfortably in them. Therefore, it is necessary to obtain knowledge and experience about the architecture, the life and user behaviour, and user needs in low energy buildings, in order to optimise and improve the next generation of low energy homes. The focus of this paper is to communicate how the occupants of some of the first Danish passive houses – the Comfort Houses experience, the passive house architecture and technical services systems, as well as to illustrate if their life and everyday practices have changed by moving into a passive house. Furthermore, this paper will illustrate how the occupants use the house and if the house meets their needs and wishes. This knowledge can facilitate the future production and use of Danish passive houses because the occupants are seen as representatives of the target group of this type of house and they will represent the future occupants or owners of passive houses. In order to investigate this aspect, focus group interviews with the occupants have been conducted where the occupants explain about their life both in the previous home and in the passive house based on the theories of *everyday life*, which are appropriate theories when you want to gain insight into people's life-worlds.

The introduction, chapter 1, continues by explaining the case study of this research project and is followed by descriptions of examples of similar research projects, which will be used later in a comparison and discussion of the results. The second chapter explains the theoretical point of departure of everyday practices followed by an explanation of the methodology of data collection in chapter three. Chapter four describes the models of everyday life from which the results is evaluated and discussed. The result will be presented case by case in *Findings – Everyday Life in Comfort Houses*, and the paper will conclude with a comparison and discussion of firstly the findings regarding the Comfort Houses, and then comparing those results with similar research projects.

Figure 1. Villa Vision, Development project by the Danish Technological Institute, finished in 1994. It is a round house with a sun space in the middle. The solar shading is triangular sails that become a characteristic expression of the house (Moltke et al. 1997).

Figure 2. Friland, Djursland – is a self-builder area in Denmark where they focus on energy use, natural and recycle materials, wastewater cleaning etc. The self-builder area was founded in 2002. (www.fbbb.dk).

The Comfort Houses

A way to reach future energy goals in new buildings is, as mentioned above, to build passive houses according to the passive house standard defined by the Passive House Institute in Darmstadt, Germany (www.passiv.de). In Germany, Austria and Switzerland they have constructed passive houses since the beginning of the 1990s and the standard is very well acknowledged both in the society and in the building industry. Today, it is also the most acknowledged passive house standard internationally.

Figure 3. Examples of passive houses in Austria (private photos).

In recent years, Denmark has also started to build passive houses but the industry cannot copy the concept directly from Germany because the demands and expectations from the user and future buyers are different as well as there being differences in building traditions. Therefore, the Danish industry is still searching for its own approach. A pilot project, called the Comfort Houses, features some of the first certified passive houses in Denmark (Komfort Husene, 2010 and www.komforthusene.dk). The project is a demonstration project of how to solve the energy challenge of the future. In addition to fulfilling the passive house criteria, the development of the Comfort Houses focuses especially on comfort and the houses are designed within Danish architectural tradition. The vision has been to create a link between passive houses and comfortable houses. The initiators had two reasons for that. Firstly, by building passive houses to automatically fulfil some comfort aspects like warm surface temperatures and no draught because of the very well insulated and airtight building envelope, and good air quality because of the mechanical ventilation. Secondly, it was believed that the term comfort appealed more to the buyers than the term passive houses and energy savings. The project the Comfort Houses consists of ten single-family houses which are different in terms of size, materials, style, construction, installations, equipment etc. and represent Danish modern and traditional single-family houses. Eight of these were certified as passive houses according to the German Standard. These are presented in figure 4.

Figure 4. Overview of the eight certified passive houses (Komfort Husene, 2010).

Other Research Projects about the use of Passive House

Similar research about passive houses and the experience of the occupants has been conducted in other countries. In the following, some examples will be presented. However, they differ somewhat in their point of departure as size of the projects, theories and methods are different from the study presented in this paper.

The first project is connected to CEPHEUS – Cost Efficient Passive Houses as European Standards, a project supported by the European Union. The project has tested and proved the viability of the Passive House concept at European level – in Germany, Sweden, Austria, Switzerland and France (Feist et al. 2001 and Schnieders, 2006). In connection with this, a passive house project in Kronsberg, Germany was evaluated, see figure 5. The objective was to assess the occupants' behaviour and management of the different technical elements. Additionally, experiences with the adaptation, the comfort and the user-friendliness of the house was collected (Danner 2001). The results are based on both quantitative questionnaires (around 1000 replies) and qualitative interviews (26 households) over a two-year period. However, the presented result seems mostly based on the questionnaires. The relevant conclusions to this research were as follows:

- Adaptation to the technical components was mainly positive
- But the occupants needed to get used to not having the possibility of regulating the temperature in each room.
- The thermal indoor environments were evaluated positively both in summer and in winter by the occupants, but 40% of the homes have invested in additional solar shading.
- It is important to have a high level of information about the operation of the passive house and the occupants believed that it ought to be repeated.
- Overall, the report concludes that the passive house is a success as 96% of the occupants are satisfied with living in a passive house.

In an extensive survey like this, problems, dilemmas or challenges can “disappear” in the positive responses and may not be addressed. The author of this paper believes that the above research, to some extent, makes overly positive conclusions. E.g. it is concluded that most occupants are satisfied with the temperature but actually 20% think it is too cold in the house. Is that the level of success? Another critique of the survey concerns some of the questions where options were missing, e.g. the question about bedroom temperature only presented two possible answers – *satisfied* and *too warm* – what were the occupants suppose to answer if they felt it was too cold? To sum up, it is important to be aware of this critique when comparing the results with qualitative results which can be more varied.

Figure 5: The passive terraced houses in Kronsberg, Hannover, Germany which is a part of CEPHEUS (Feist, W. at al. 2005).

In Sweden, they started to build passive houses earlier than in Denmark. Two research works, both based on terraced houses in Lindås Park in Gothenburg, will be described in the following. The first project is a multidisciplinary work which presents several aspects in terms of the construction process, the user behaviour and opinion about the s are the user behaviour and their opinion about the house. The objective of this research was to investigate how the occupants use the building and the techniques, in addition to how they experience and can influence the indoor environment. The data is collected from interviews with 16 households. The main conclusions were (Boström et al. 2003):

- Most occupants experience uneven temperatures in the house, both between rooms and floors; nevertheless, most do not think it matters that some rooms are cooler because candlelight and equipment will heat it up during the day.
- Several occupants point out the effect of the weather on the indoor temperature, when the sun is shining, it is much warmer in the house compared to when it is cloudy.
- Most occupants experience that it is too hot in the summer. All use natural ventilation to cool the house. About half of the occupants bought awnings, where others used curtains to shade indoor areas from the sun.

- During winter, most occupants were satisfied with the air quality and only a few opened the window in the bedroom a little in the morning.
- Generally, all occupants think that the information about the management of the heating system was insufficient.

Figure 6. Pictures of the passive terraced houses in Lindås Park in Sweden (www.passivhuscentrum.se/lindas_ radhus.html).

Charlotta Isaksson also took part in the above report but her final thesis focuses more on the domestication of how to handle the technologies in the passive house based on the occupants' previous knowledge. Therefore she has conducted more interviews to register the learning processes with the technical installations over time as they lived in the passive house. The objective was to find out how the occupants use, choose and relate to the technique of the heating and ventilation in the home, with the focus on domestication (Isakson, 2009). The results were:

- Some are very committed to learn about the techniques in the beginning but as time passes their interest fades. Others do not touch anything because they are afraid of the technology.
- The manuals are difficult to understand because the occupants lack the knowledge to interpret the information.
- Gradually, the occupants get more confident with how to manage the heating in the passive house, but generally most people did not know how a thermostat worked.
- The occupants had to learn how to manage the variations in temperature in connection to e.g. sun and visitors as it is important to know the limits and possibilities of the heating and ventilation technique. The occupants are forced to notice the thermal comfort in the house to be able to take action according to it.

The research in this paper takes a different approach than the above mentioned researches. In addition to taking a different theoretical departure, which will be described in the next section, this research will communicate new knowledge about the experiences, life and behaviour in passive houses in a Danish context, which undoubtedly have had a different design process and are founded in a different tradition than the cases described above. Additionally, the scope of this project is less extensive as it deals with only three cases and the type of dwellings are single-family houses with individual designs, where the above research is based on terraced houses and blocks of flats. With the few cases in this study, it is possible to go into more detail with the everyday life, however; the possibility of generalising is very limited. The different research projects presented above also differ in objective and theoretical starting point but the investigation centres around the same topics. Charlotta Isaksson investigates from a learning perspective (domestification), the multidisciplinary report by Boström et al. investigates the actual user behaviour and finally, the report about passive houses in Krongberg focuses mainly on the adaptation to living in a passive house. Overall, they centre around the everyday life and its practices which are the main focus of this research. None of the above mentioned research uses a direct comparison between the occupants' lives and practices in their previous home and what changes life in a passive house can result in. However, since they do it somewhat indirectly it will later be possible to compare their results with the findings of this paper.

In the following, the paper will use both the term *passive house standard* and *passive house concept*. *Passive house standard* refers to the German certification standard from the Passive House institute, where *passive house concept* is used when referring to the principles of the construction, which is needed to fulfil the passive house standard. The concept of passive houses is also usable in other kinds of low energy housing.

Theoretical point of departure

To examine the everyday life of the occupants and the changes they have gone through, theories of everyday life sociology are used. Broadly speaking, three directions or tendencies of approaches dominate; firstly, the creator of phenomenological sociology Alfred Schutz; secondly, micro sociology by Erving Goffman; and lastly, critical theory by Agnes Heller (Calhoun, 2007). Theories of Alfred Schutz (Schutz, 2005) supported by theories of Birte Bech-Jørgensen (Bech-Jørgensen, 1994, 1997 and 2002) are used in this research because they take as their starting point everyday life and analyse its principles. Everyday life is a metaphor for the daily life that we live. Not just outside work, but also family, the local area etc. are part of the life in its totality. Everyday life is an ill-defined term. It is not an analytical term, but a term that can be analysed. Everyday life is created when people *manage* their *conditions* – a perspective the paper will get back to. The everyday life changes all the time even though it can be difficult to see it in the moment. Every movement and event influences the everyday life, even though the everyday life coheres by habits and routines. It is like a river. Looking at the river every day it seems the same at first glance, but the water today is different from yesterday. The water erodes the bank, moves the stones and lets the plants grow etc. The everyday life is therefore always changing, but we may not notice the changes. (Beck-Jørgensen 2002) Both Alfred Schutz and Birte Beck-Jørgensen work with the concept of *common-sense* which in its construction makes it possible to describe and categorise a certain everyday life. The notion of common-sense is described in the following quote:

"All our knowledge of the world, in common-sense as well as in scientific thinking, involves constructs, i.e., a set of abstractions, generalizations, formalizations, idealizations specific to the respective level of thought organization. Strictly speaking, there are no such things as facts, pure and simple. All facts are from the outset facts selected from universal context by the activities of our mind. They are, therefore, always interpreted facts, either facts looked at as detached from their context by an artificial abstraction or facts considered in their particular setting. In either case, they carry along their interpretational inner and outer horizon. This does not mean that, in daily life or in science, we are unable to grasp the reality of the world. It just means that we grasp merely certain aspects of it, namely those which are relevant to us either for carrying on our business of living or from the point of view of a body of accepted rules of procedure of thinking called the method of science." (Schutz, 1973, b: 5).

The concept of *common-sense* is a kind of natural attitude which can describe life - how it seems given and natural. The natural attitude exists here and now both to oneself but also to others, and it has a past and a present. The natural attitude derives from storage of cultural and social knowledge which we, unheeded, draw upon when we recall the commonplace of the everyday life. The subjective opinion or action is unique and individual to the actor because it rises from the actor's own unique and individual biographically determined situation. *Common-sense* is construction of the reality of everyday life, which determines certain behaviour and defines the goal of the behaviour. Compared to natural science where the scientist is concerned with facts and data within his observation field, which has no impact on e.g. the molecules, atoms and electrons within that. The social scientist on the other hand is concerned with human's living, thinking and behaviour, which has a system of relevancy inherently based on the unique biographical situation. To be able to understand the subjective opinions, *scientifically designed models* of a part of the social world should be defined. In scientific work, the researcher takes an unbiased position – one disengages oneself from one's own biographical situation and questions the *taking for granted*. The *models* are designed patterns of typical courses of action that are relevant to the scientific problem – therefore all irrelevance is removed and the *models* have no biographical situation. The *model*s are fragments of the actor's behaviour, but the researcher creates common-sense constructions on the basis of his/her scientific corpus. It is a different structure than the one the actor has available in his/her everyday life. The scientific problem is therefore the issue that determines the system of relevancy (Schutz, 2005). To be able to "measure" the everyday life of the occupants, *models* of certain experiences and/or behaviour of the occupants in the Comfort Houses are described. They are presented later in the paper.

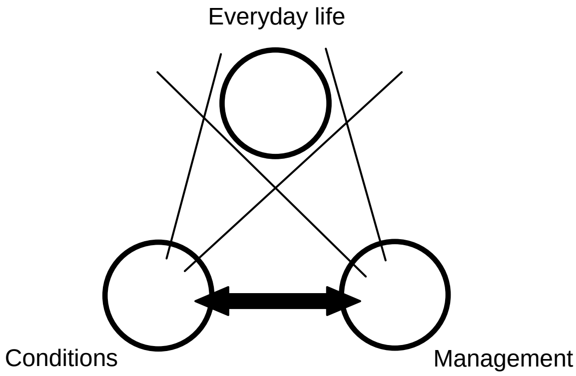


Figure 7. Double perspective by Birte Bech-Jørgensen, 1997.

Birte Bech-Jørgensen states that by using a double perspective you get an understanding of people's everyday life. The everyday life has to be observed from the *conditions* of a certain everyday life (perspective 1) and how the people *manage* the everyday activities according to the *conditions* (perspective 2) as illustrated in figure 7. (*Manage* is translated from the Danish term "håndtering" and *conditions* are translated from "betingelser"). Analytically the everyday life is separated in two parts, but it is only an analytical separation. In practice they will not be experienced as separated, but as a unity – a way of living. The *conditions* of the everyday life are described from the outside with an objective perspective on general social conditions, like demography, environments or institutions. The *conditions* can be highly complex and comprehensive; therefore it is necessary to select the important *conditions* for a specific everyday life (Bech-Jørgensen, 1997 and 2002). Birte Bech-Jørgensen defines three sets of *conditions* (terms are translated from Danish). First is the *symbolic natural order*, which has to do with what seems so natural that one believes it is part of the natural laws. The two others are the *institutions of the society*, like the family, the job market, the public sector etc.; and the *universe of sense-making*, where people create meaning and coherence in the activities in the everyday life. The other part of the double perspective is the *management* of the everyday life. The questions about how people manage or handle the *conditions* of the investigated are the most essential. It is about the daily activities, which also include emotions. It is about seeing, hearing and experiencing the relations between the investigated parts and about the adjustment to possibilities, limitations and changes (Beck-Jørgensen 1997). The analysis of the everyday life starts in the activities which are constantly reproduced and reshaped within the conditions. A large part of the activities we do unnoticed – meaning the things we do which we do not notice we do. However, it is not the same as doing the activities unconsciously (Bech-Jørgensen, 1994). It is exemplified in the following:

"If someone makes me aware of what I just do unnoticed, then I know I do it and can immediately talk about it. I may be surprised that others have noticed something I do, which I have not noticed my self, - I can laugh about it, be annoyed by it, think about it. But I do not block against being aware of it." (Translated from Danish, Bech-Jørgensen, 1994 b:17)

This is the central focus of this study, i.e. to find out what the occupants do unnoticed both in their previous home and in the Comfort House and thereby illustrate changes in the everyday life. This approach makes it possible to frame the everyday life by discussing the *conditions* in relation to how the occupants *manage* those. The *conditions* can e.g. be general social conditions, demography, environments or institutions. Birte Bech-Jørgensen's research is about the interaction between people in a social environment or institution but in this research it is about the meeting between people and the passive houses and the expectations of the building industry. Therefore, the *conditions* in this research are some of the demographics of the occupants and relevant characteristics of the architecture of the Comfort House; meaning both the layout and functional aspects of the house and the passive and active technologies of the house. The focus is therefore the occupants' meeting with the passive house and how that affects the everyday life of the occupants. This will be further explained in the *scientifically designed models* which are presented later.

Method

The methods of evaluating the occupants' opinion depend greatly on the theoretical point of departure and the kind of knowledge the research is intended to produce. One of the examples mentioned in the introduction has used questionnaires which is a suitable solution when the amount of cases (or respondents) is high and one wants to produce statistics (Bryman 2008). But in this research, where the cases are few and one wants to understand the person or group of people's life-worlds, interviews are more suitable. Semi-structured interviews are flexible in design which means that the interviewer can change the order of the questions in the question guide and follow-up with extra questions on relevant topics that occur during the conversation. A conversation also allows dialogue; achieving a common understanding of the discussion, and the interviewer can change or clarify the question if the interviewee does not understand it etc. (Kvale 1997).

"…interviews are especially suitable when investigating people's understanding of the meanings in their life-worlds, describe their experiences and self-understanding and clarify and elaborate on their own perspective on their world (Translated from a Danish edition, Kvale 1997, b: 111).

Therefore, the method of semi-structured interviews can produce knowledge about the everyday life in the Comfort Houses which is the aim of this research. The interviews will cover both the *conditions* seen from the occupants' point of view and how they experience *managing* the conditions, which by the theory of Birte Bech-Jørgensen will illuminate the everyday life. The process of interviewing gives the interviewer the possibility of asking, discussing and elaborating in the specific case, which would not be possible in the same way with e.g.. questionnaires, because of the lack of flexibility according to the situation - each case has individual *conditions*.

The data collection is conducted through two semi-structured interviews with the occupants; firstly, about their previous home and secondly, about their new home – the Comfort House. The first interview will illustrate the perception of the former house and their everyday life. This knowledge is compared with the findings of the second interview focusing on the occupants' perceptions of living in a Comfort House. This illustrates if the occupants' expectations and requirements for the dwelling are fulfilled and if the new housing has resulted in a different everyday life than they had before moving in. In order for the family to still have their previous home in mind, the first interview was conducted quickly after the family moved into the Comfort House. The second interview had to be conducted after the families had become fairly used to living in the house and they had experienced at least one summer and winter in the house, because the investigated topics are highly dependent on the seasons, which the paper will return to later. The second interviews were conducted six to ten months after moving in.

By taking the approach of everyday life, it can be discussed if the time where they have lived in the houses before the second interview has been long enough – the change in everyday life is dependent on time. Two days will never be exactly the same but the family would still have the same routines and habits as yesterday. The term everyday life can be expressed like this:

"Everyday life is consequently not a substantial notion, it is a procedural notion, i.e. everyday life is created and recreated, maintained and renewed, and this happens through the ways that people manage their conditions" (Translated from Danish, Bech-Jørgensen, 1997, b: 9)

Therefore, the question is whether the time of the second interview was appropriate. Can the change in the everyday life be "measured" and compared to the everyday life in their previous home at this time? This dilemma is partly accommodated by comparing the results with other similar studies regarding the level of agreement even though the geographical context and scope of the research are a little different. Additionally, the different topics are discussed regarding how and if the result could have been different if the occupants have lived longer in the Comfort House before second interview. The research period could unfortunately not be extended because this study is part of a PhD thesis with a time limit.

Models of everyday life in the Comfort Houses

As stated by Alfred Schutz, to grasp the everyday life of the occupants and use *common-senses*, *models* of typical courses of action that are relevant to the investigation are described. The *models* have no biographical situation and all irrelevance is removed. The models can also be seen as a kind of hypothesis which this study wants to confirm or disconfirm. The *models* make it possible to "measure" if the houses function as they were planned and if the residents have changed practices in their everyday life as a consequence of living in the Comfort House. In the following, *models* of different experiences and behaviours in relation to its *conditions* are described. The everyday life unfolds in a social context, but also in a physical and functional context, which is sharply in focus in this research – the changing *condition* that might affect the everyday life. Firstly, the models reflect the everyday practices that are connected to the building concept of passive houses. Regular everyday practices like cooking, laundry and cleaning are not directly interesting because they are expected to stay the same whether you live in a passive house or in a “traditional” house. But everyday practices like ventilation and solar shading practices, regulation of the temperature, living behaviour with transparent facades etc. could change by moving into a passive house compared to living in a “traditional” house, because of the fact that the physical *conditions* – the house, is changed. Secondly, models are developed from the myths and expectations in the building industry – an institution of the society (a *condition*), about how it is to live in a passive house and what potential problems that could occur. The models are defined in the following.

Transparent facades: Passive houses in central and northern Europe often have transparent facades to the south in order to increase passive solar heat gain into the house through the windows. Therefore, it is expected that some occupants might feel too exposed through the large windows to the south and that this would result in a change of behaviour; either in staying away from the windows or using curtains or blinds. Said in the terms of Birte Beck-Jørgensen it is expected that the change in layout of the house – the *conditions* – results in another way of *managing* within those *conditions* – a change in the everyday life. The potential problem of feeling too exposed by the transparent facade is intensified in the wintertime when the exposure of the life within is emphasised by the darkness outside and artificial light inside. Then the occupants might pull the curtains so the neighbours and passers-by cannot look inside

Excess temperatures: Because of the large amount of window area to the south which most passive houses have, there is a great risk of excess temperatures if no precaution is taken. It is expected that if the houses do have excess temperatures (the *condition*), the occupants have got used to solving the problem (*manage* the problem) as a part of their everyday life, by e.g. using solar shading, use of manual natural ventilation or installing air-conditioning.

Passive house windows and the deep embrasures: A physical characteristic of the passive houses is the design of the window and the mounting within the wall (the *conditions*). The passive house windows often have triple glazing and many certified passive house windows, especially the German brands, often have thicker frames than traditional Danish windows. They are both wider and deeper which gives a more heavy expression to the windows whereas the aesthetics of a window in Denmark is often connected to the slimness of the frame. Additionally, the passive house certified windows often open inwards where Danish windows mostly open outwards. This issue is of great importance to the building industry especially in the architectural field as they prefer the slimmer look. It is expected that the occupants have become used to both the functionality and aesthetics of the windows (*management*). The embrasures around the windows in a passive house are often deeper than in “traditional” houses due to there being more insulation in the wall. Poor examples are well known in the public from houses built after the oil crises in the 1970s where windows were smaller and had deeper embrasures which, in some cases, gave poor daylight conditions (Knudstrup et al., 2009). The solution received the nickname *gun slit* and is also used in a prejudiced way about windows solutions in low energy houses of today. The design team has been aware of this and keen to avoid *gun slits*, but they cannot escape the deeper embrasures because of the thick insulation layer.. It is expected that the occupants of the Comfort Houses have become used to the architectural expression with the deeper embrasures in the house.

Figure 8. The deeper embrasures in a passive house can be used as a sitting area (Komfort Husene, 2010)

Ventilations habits: Generally, a passive house is mechanically ventilated (the *condition*), in contrast to older houses, which more often are ventilated manually with natural ventilation – window airing. Therefore, it is expected to be a new situation for the occupants to live in a house with mechanical ventilation. It is expected that the occupants have changed their habits from manual opening of the windows a number of times per day to letting the mechanical ventilation do it for them. In addition, it is expected that they have become used to adjusting the ventilation according to their needs: like "not at home", "home" and "guest", or summer operation (the *management* of the *conditions*).

Regulation of temperature: The regulation of the indoor temperature is often different in a passive house compared to a "traditional" house. The original idea of the passive house concept is to heat the houses with the ventilation air and thereby save the expenses for the traditional space heating, usually by water. This means that in this situation, the temperature is set in the ventilation unit and the inlet temperature is the same in all rooms (the *condition*). Most Comfort Houses followed that idea. However, all houses have as a minimum floor heating in the bathrooms, which the project description required. This was mainly due to comfort requirements and not so much to do with the heating of the house. Therefore, it is expected that the occupants have gotten used to not having the possibility of regulating the temperature individually in each room. It is expected that the occupants trust the automatic control system of the ventilation and the house has the right indoor environmental conditions (the *management*).

The models just described are areas where the everyday lives of the occupants in the Comfort Houses are evaluated. It is important to remember that it is the way people *manage* everyday life within the *conditions* that together form the perspective of the everyday life that take place.

Findings – Everyday Life in a Comfort House

The Comfort Houses project is a part of a larger research project with different research topics and where each house represents a case. This study is based on three cases and in order to maintain continuity across the entire study, the same case numbers are retained throughout all research topics. This also gives the reader the opportunity to conduct comparative studies across study fields by reading other publications within this research project, e.g. "*Interview Report about the Design Processes behind the ´Comfort Houses´"* (Brunsgaard, 2009) or *"Quantitative and Qualitative Evaluation of the Indoor Environment of the Comfort Houses"* (Brunsgaard et al., 2010). This study focuses on case 2, 7 and 8. Originally the idea was to sell the houses on the normal housing market but at the time of completion the financial crisis occurred. Instead, the houses were rented out because it was not possible to sell them. This means that the occupants most likely feel less ownership of the house and therefore have little or no expectations as to the performance of the house.

The occupants are promised anonymity, and therefore pictures or drawings in the following will not directly reveal which houses the cases represent. The illustrations will consequently be conceptualised in a way that the idea is conveyed without revealing the actual house and thereby the occupants.

In the following, findings about each case are presented on a case-by-case basis. Later, a cross case comparative study is made. The case-by-case presentation starts with a presentation of the actual case and description of some of the conditions. This is followed by the description of the occupants' experience of the architecture. Finally, findings according to the everyday models in the Comfort Houses are presented and discussed in relation to the everyday life in the previous home and thereby illustrate any changes by moving into a Comfort House.

Table 1. The table gives an overview of the characteristics of the houses and the families' motivations for moving into a Comfort House.

	Case 2	**Case 7**	**Case 8**
Characteristic of the Comfort House	• One story house • Modern and cubic • 169m^2 (gross area) • Three bedroom. • One flexible space (used for bedroom) • Heating by ventilation air, temperature control in the unit • Floor heating in the bathroom • The solar shading is a permanent overhang by the southern windows	• One story house • Traditional style • 177m^2 (gross area) • Four bedrooms • Heating by ventilation air, temperature control in the unit • Floor heating in some areas of the house. • The solar shading is a permanent overhang by the southern windows	• Two story house • Modern and cubic • 198m^2 (gross area) • Three bedrooms • Landing area (used for office) • Heating by the ventilation air, temperature control in the unit • Floor heating in the bathrooms and one backup radiator in the living room • There are no solar shading of the southern windows
Motivation for moving into a Comfort House	• Not ready to invest in a house, renting possibility • Good neighbourhood, close to school and recreational areas • Like the open plan of the house and needs 4 rooms • Like the idea about passive houses	• Found the house through a colleague • Needed to rent a house • Important with space, peace and quietness	• They almost bought the house but was sceptic. Renting gave the possibility to try it out • They wanted a new house that needed minimum of maintenance • Needed a large house outside the city but yet still close to the city

Case 2
The family in case 2 consists of a mother and her three children. Occasionally, her boyfriend also stays in the house; sometimes with his child. The family also has a cat. The mother was not born in Denmark but she has lived in Denmark for the last 13 years; all children were born in Denmark. Previously the family lived in an old brick single family house from 1910. They renovated the house over several years. The motivations for moving into a Comfort House and some of the main characteristics are listed in table 1.

Table 2. The table shows a summary of the occupants' most essential experiences with the architecture.

Case 2	
Qualities	**Problems**
• The open plan supports the notion of being together as a family. • Good layout of the house – the open plan; arrangement and interrelationship of the functions and rooms. • Good daylight and nice view to the outside. • Like modern style of the house. • The materials harmonise well.	• Lack of storage, occupant express that it might be because of the minimalistic expression. • Feel exposed to the people passing on the street both inside and when sitting on the terrace, but like the light from the large windows. • Closed blinds give feeling of living in a box. • The house needs a woodstove and a bathtub to be a real home.

The most essential experiences of the occupants about the architecture are listed in table 2 and divided into qualities and problems. Overall, they like the architecture of the house, especially the layout of the house, the style, the materials and the open plan. The latter has resulted in more family time compared to what they had in their previous home:

" We had an entire annex where the children were ... (and) there was an entire playroom ... it was not only physically far away because there were large rooms but there were walls to the kitchen and our living room. There was no contact ... even though we were all on the ground floor most of the time, we were not together very often ... Then I missed the open plan which we have now. I am extremely pleased that we have time together in this space because you spend a lot of time in the kitchen when you have many children. I spend a lot of time shopping for food, preparing food, cleaning up and washing clothes and hanging them up." (Case 2).

The architectural problems are of a more functional character. Some of the problems are not directly related to the passive houses concept, like e.g. lack of storage. Others are a specific result of the passive house concept e.g. the feeling of being too exposed through the large windows to the south which is a consequence of achieving solar heat gains in the winter. It results in a feeling of living in a box when closing the blinds to be more private. It is a dilemma for the occupants because they like the daylight from the large windows:

"…(the blinds can) take some of the light which is a bit of a disadvantage sometimes. But it is also nice because (the house) is placed orientated to the bike path (and the street), and you can get a little privacy (with the blinds) ... so we are closing them because we are very exposed, people can see everything that goes on in the house ... it's ok (that we have to close the blinds) ... but you feel a little box-like inside ... I have a tendency to say that it can not be otherwise ... it is also nice with the large windows, there are advantages and disadvantages." (Case 2).

The above statement is directly connected to the everyday life model of *transparent facades*. The feeling of being exposed results in opening and closing of the blinds during the day which has become an important part of their daily practices. Their reason for doing this is believed to be connected to the conditions of the site – how the house and the site are placed in relation to the public. The window area and the placement of the house according to the context are the *conditions* of how the everyday life is *managed* **-** the practise of managing the privacy and *feeling box-like*. In this case, the large windows are facing the street to the south, which makes the house more exposed to the public than some of the other houses; see the first illustration in figure 13. **.**

The design of the southern facade is also directly connected to the experience of *excess temperatures*. In the occupants' previous home, they did not have any experience with excess temperatures. In contrast, they experienced the house as being very chilly in the summer. In the Comfort House, the occupants need to act because they experience that it is too hot in the summertime, despite the fact that the house has an overhang on the southern orientated windows, see figure 13. To deal with the problem, they have put up internal shading to reduce the heat gains as well as to create privacy as mentioned above. They also try to solve the problem with natural ventilation by opening windows and doors and sometimes taking off more cloths; however, they still think it is too hot. Parallel to this study, a measuring program is documenting the indoor environment

by quantitative measurement (Measurement program, 2009 and Brunsgaard et al., 2010). Figure 9 illustrates that a comfortable indoor environment in the summer period (temperatures between 23 and 26°C) is achieved at approx. 50% of the time while 237 hours of a month are above 26°C. Comparing the temperature curve with the curve of the outdoor temperature, it shows that the temperature outside is only above 26°C in the first 4 days of the month, which means that for the remaining part of the month the indoor temperature can be ventilated naturally to cool the building. Therefore, the measurements support the experiences of the occupants. In addition, the curve of the indoor temperature shows that the temperature peaks at the end of the day, which is a normal tendency, but in this case it can also be the result of the relatively large windows to the west (illustrated in figure 13), which the overhang cannot shade in the evening.
Getting back to the everyday life of the occupants the excess temperature is a *condition* of the everyday life that is *managed* by using natural ventilation and blinds – a practise they did not have in their previous home.

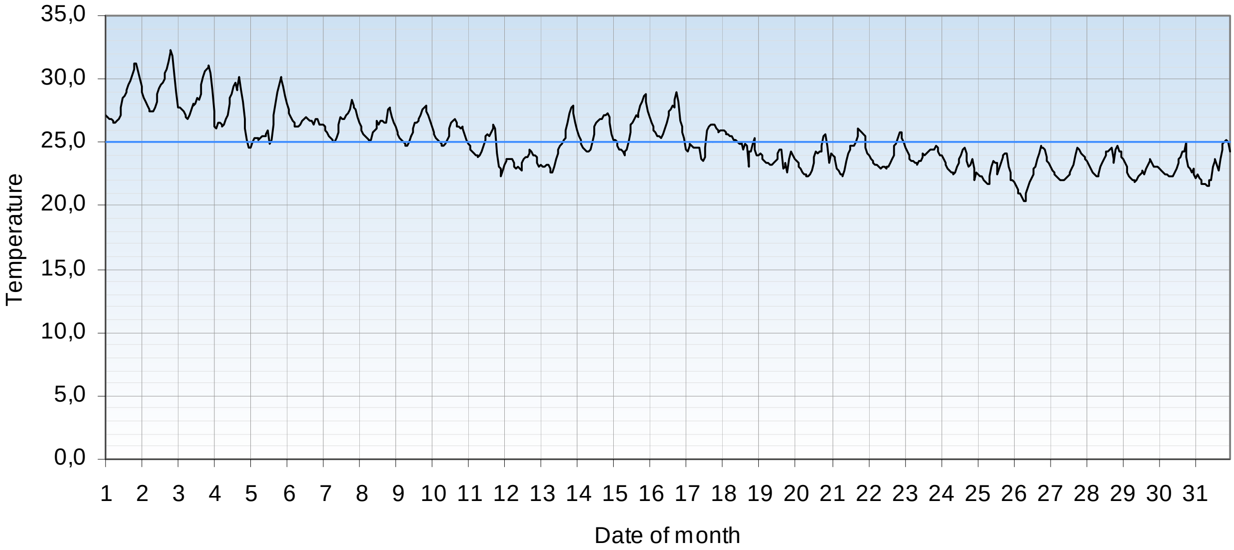


Figure 9: The figure illustrates the indoor temperature in the living room in case 2 in July 2009. The straight blue line is the average temperature.

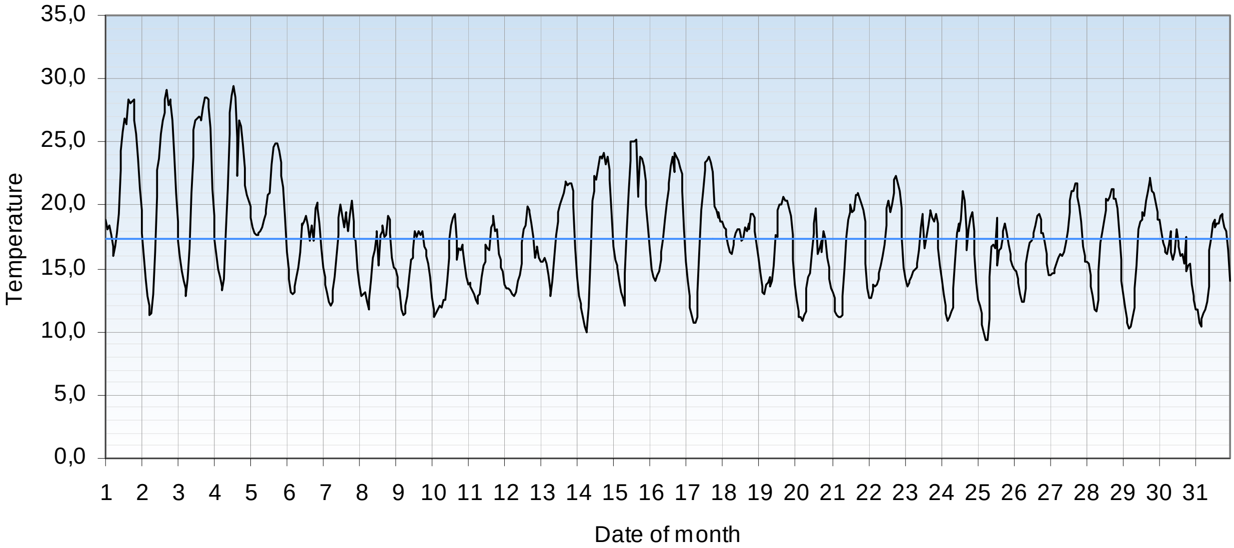


Figure 10: The figure illustrates the outdoor temperature in July 2009. The straight blue line is the average temperature.

According to the expression of the *passive house windows and the deep embrasures,* the occupants have gotten used to the deeper embrasure and the occupants just think it is a natural result of low energy houses.

“The depth of the embrasure is something people notice a lot and I think it is very interesting that people are so surprised by it. But it is clearly a conscious choice to be able to save energy, therefore it is good ... It is no problem other than it takes up some of the area which they advertised as the size of the house . ... My cat loves it (the windowsill) but no one in the family uses it actively.” (Case 2)

The embrasure is therefore not used for sitting by the occupants, which might be cause of the *conditions*. The wall is approx. 455 mm thick and the windows are placed 120 mm into the wall, which means that the inner windowsill is approx. 200 mm, more or less the same depth as in a “traditional” house, and therefore not obvious to use it for e.g. sitting see figure 14. Therefore the *conditions* (the depth of the window sill) have not changed from the previous home and therefore no changes in the everyday practises are registered – the *management* is the same. The occupants think it is fine that the window frames are thicker than they are used to – she like the colour and appearance of them.

The *ventilation habits* regarding air quality has not changed for the occupants. They ventilate the house by window airing every morning as they were used to in their previous home. The occupants think that there is a need for it. In other words, the occupants do not think the air quality is good enough, even though it was supposed to be automated by the ventilation system itself. They do not use the ventilation according to their needs, e.g. turning it up when they have guests or turning it down when they are out, they do not know how. They were told that it runs as it should and therefore they do not touch it. In any event, they do not trust it.

The occupants would like to have the possibility to *regulate the temperature* because generally, it was too cold in the house in the winter period and they sometimes had to use skiing underwear. The problem with the temperature was investigated by the owner of the house and it showed that the designed capacity of the heating system was too low. In other words, the occupants could not have done anything about it. Next winter it will become clear if the solutions made are sufficient. At any rate, the occupants do not feel that they have the knowledge, courage and trust in the systems and it is therefore interpreted that the occupants prefer a controlling system that they are more familiar with.

Case 7

The family consists of two adults and one child. The family has lived in Denmark less than a year; therefore their frame of reference is from nations and cultures other than Danish. They have lived in several countries over the last 6-7 years. Some of the main characteristics of the house and their motivations for moving into a Comfort House are listed in table 1.

Table 3 lists the most essential qualities and problems the occupants express about the architecture. Overall they like the architecture of the house, especially regarding size and functionality and they emphasise the quality of the open plan. It results in more time to be together as a family, because they can all be in the kitchen and living room at the same time, like the family in case 2 also expresses. The lack of windows in the bathroom is a result of the passive house concept to minimise the heat loss through the building envelope. It has been a conscious choice by the design team (Brunsgaard, 2009), but the occupants miss the daylight. The problem with lack of shelter in the outdoor area is not directly linked to the passive house concept and it can be solved through time by planting trees or the like to create more shelter.

Table 3 . The table shows a summary of the occupants' most essential experiences with the architecture.

Case 7	
Qualities	**Problems**
• Generally satisfied with the house, both the functionality, the sizes etc. • Good layout of the house; arrangement and interrelationship of the functions and rooms, especially the open plan. • Open kitchen-dining area result in more "being together" in the family. • Direct access to the bathroom from bedroom.	• Miss window in the bathroom (north orientated). • Would like to create more shelter in the outdoor area if they owned the house.

The occupants in case 7 only feel exposed through the southern windows at night, where the darkness enhances the life inside, therefore they close the curtains to be more private. During the day they do not feel so exposed because the neighbour to the south lives "on the opposite side" of the house – meaning that the neighbour's north façade is also more opaque and their family rooms are also placed to the south, see figure 13. Therefore the opening and closing of the curtains has become an everyday practice in the evening in order to achieve privacy – *management* of the *conditions* (the southern orientated windows), which create a new everyday practise.

Regarding the *excess temperatures*, they experience the house to be very hot in the summertime even though precaution has been taken by way of a permanent overhang on the southern orientated windows, see figure 13. They sometimes use the internal shading, which they think helps a little, but they mainly try to solve the problem with natural ventilation by opening windows and doors.

"It is too hot, it is really really hot. We use natural ventilation, but we are thinking of buying an airconditioner. In this case they (the owner) have to do something about it here, because it is really really warm." (Case 7)

The statement of *"thinking of buying an air-conditioner"* is interpreted to be a way of saying that the situation today is not acceptable and other thermal conditions are necessary. The measurements also confirm the occupants' experiences. The temperature is outside the comfortable level (max. 26°C) approx. 70% of the time in July, see figure 11.

Nevertheless, they are today more aware of the use of natural ventilation and use of the curtains as part of their everyday practise – a practise they consider to change by installing an air-conditioner.

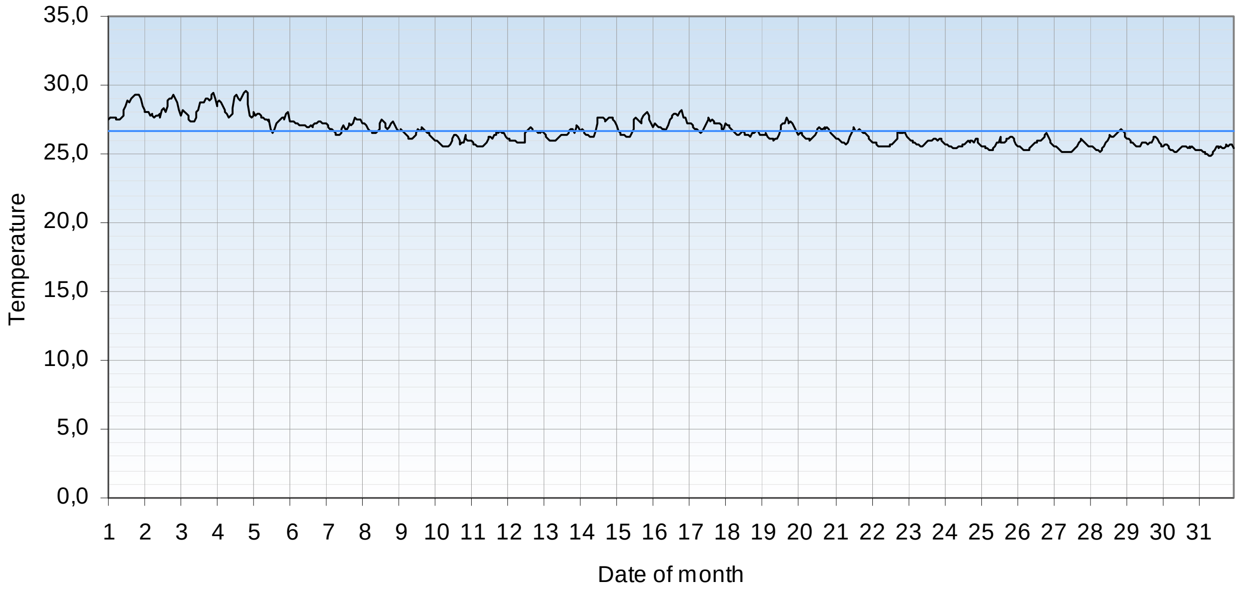


Figure 11: The figure illustrates the indoor temperature in case 7 in July 2009. The straight blue line is the average temperature.

The occupants have not noticed that the *embrasure* is deeper than in "traditional" houses, they think the floor-length windows might be the reason. Neither does it bothers them that the frames of the *passive house windows* are thicker and they have not noticed that they open inward. According to their point of view the difference in cultural background (a *condition* of this everyday life) may come into play. Because they have lived less than a year in Denmark, they are not so familiar with Danish window solutions and maybe used to other solutions from other countries.

The *ventilation habits* of the occupants have changed, because the mechanical ventilation system is now doing it for them and they do not have to open the windows – it is a very positive experience. Previously they both had to manually open the windows and turn on and off the heat – a change in the *conditions* that affect the everyday life positively. They do not change the ventilation rate according to their needs, like when they are out of the house or on holiday, but they turn it up e.g. when they have guests. They think it is very easy because they only have to push one button and then the ventilation rate is higher for an hour. The only problem they came across was that they did not know they had to manually change between summer and winter operation. Today they know and think it is very easy. Even though they have a generally positive experience with the mechanical ventilation system, they miss the possibility to *regulate the temperature* especially in the living room, where they would like 1-2 degrees higher. They express it in this way:

" I think the indoor environment is really really good, especially in the sleeping room. The only thing is that sometimes here in winter we would like it a little warmer, but we can only get a maximum of 20 degrees here (in the living/dining room) and it's sometimes cold. In the evening you can never walk around in your … T-shirt, because it is a little cool. But the air is fresh and good ... When the sun shines in winter we do not experience any problems (with the temperature), then we get 2-3 degrees more in the house, which is perfect." (Case 7)

Furthermore they say that they have been in contact with the plumber and he thinks it is possible to raise the temperature in the ventilation system. Whether this has been possible and how it has influenced their experiences, this study does not show.

Case 8

The family in the final case consists of two adults, two children and a cat. All family members were born and raised in Denmark. Before moving into the Comfort House they lived for a short period of time in a flat and before that they lived in a house, which they renovated and rebuilt over many years –

a lot of the husband's spare time was used on the house. In table 1 the motivation for moving into the Comfort House is listed together with some of the main characteristics of the house.

Table 4. The table shows a summary of the occupants' most essential experiences with the architecture.

Case 8	
Qualities	**Problems**
• Seams generally satisfied with the architecture of the house (short answers). • Good layout of the house; arrangement and interrelationship of the functions and rooms. • Good daylight conditions. • Fantastic view from the house.	• Very dissatisfied with plenty of things according to workmanship, quality of solutions and legal requirements. • Thinks that there has been made wrong financial prioritisation in the project. • One room could have had more daylight. • Would like to have more shelter in the outdoor areas.

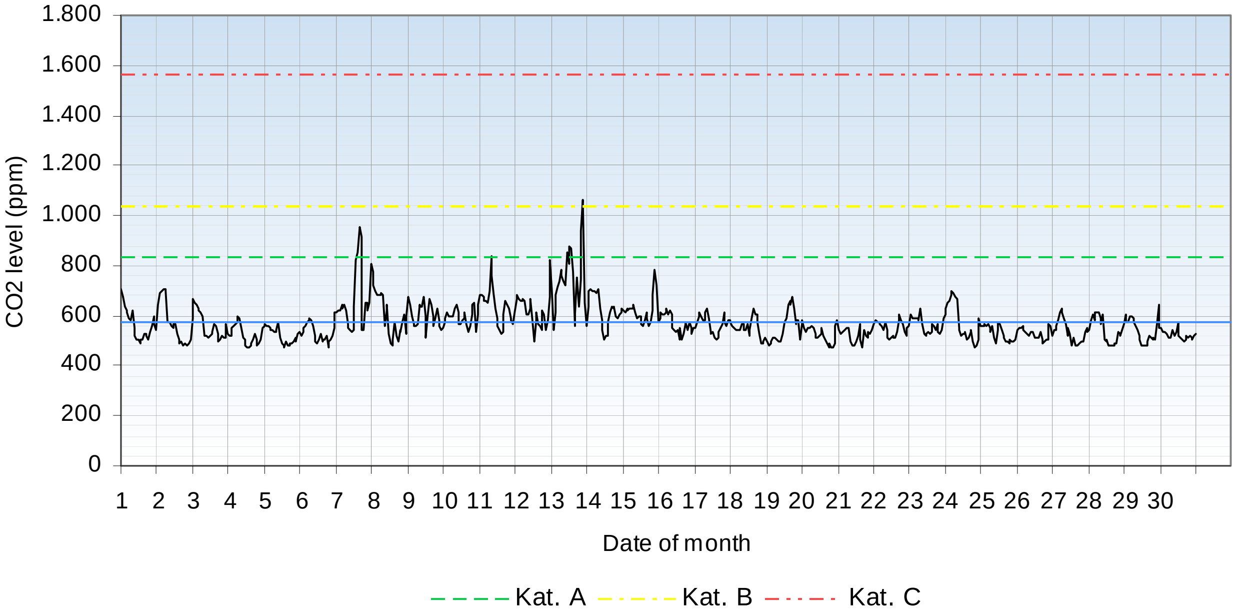
The most essential experiences, which the occupants express about the architecture, are listed in table 4. Offhand, the occupants seem satisfied with the architecture. However, it cannot be concluded definitively, because the occupants gave very short answers and had more focus on quality of the workmanship and legal requirements of the house and on the whole expressed plenty of dissatisfaction. The workmanship has more to do with the design, construction and economy of the house, than the passive house concept directly. This does not make the problems less important, but these are problems which also could occur in any other building projects.

The *transparent facades* present no problem in this case. The large window to the south is not a problem for the occupants either during the day or night. They felt the same way in their previous home, but they elaborate that the windows were, of course, smaller then. Despite that, the reason for them not feeling exposed may be the fact that their south façade is angled to the road (the *condition*) and therefore not directly facing the people passing by. Additionally, the house is angled to the neighbouring house, which has a more opaque north façade, which gives the occupants more privacy; see figure 13. They have therefore regarding this model of everyday life not picked up new practises.

The *window embrasures* in this case are the deepest of the three cases, approximately 400mm and the sills are placed at sitting height; see figure 14. In the beginning the occupants thought that it was impractical regarding furnishing, but in the second interview they liked the fact that you can use them for sitting and placing things. However, they do not use them for sitting because they think it is too hot to sit there and the quality of the sill is poor. To cool the sitting space down the husband suggests putting film on the windows. The *window frames* are not discussed in this interview, because they are more or less the same size like the "traditional" Danish window frames and the windows open outwards.

The occupants did not really have any *ventilation habits* in their previous home. A window was open all the time, because three of the family members are smokers. Today the ventilation system runs on the highest level, but still they do not feel that the indoor climate is comfortable, both regarding the quality of the air, but also because they feel they have been more ill since they moved in. They supplement with natural ventilation in both summer and winter by opening the windows and door when they are at home. Therefore it can be stated that the occupants have not changed their ventilation habits radically, they still supplement with natural ventilation. However, it has become more difficult because the windows and doors have trouble staying open by themselves and therefore they sometimes have to stand in the door and keep the door open. Additionally they think the amount of sections which can be opened are too few – one door and one window in the living room, one door in the kitchen, one skylight and one window in each bedroom – the rest of the windows cannot open. The measurements carried out in this project cannot tell anything about the sensory pollution load (e.g. smell from smoke, furniture and food) but the measurements of the CO_2 level is used as indicator. The measurements show a satisfying indoor air quality about 90% of the time both summer and winter, see figure 12. When there is pollution by smoking, the ventilation rate need to be increased dramatically

(CR 1752 2001), which the ventilation system is not designed for. But looking beyond that, their everyday practices with the natural ventilation have become more difficult and they are more dissatisfied with the air quality than in their previous home, because the ventilation strategy does not fit their needs – the *conditions* do not match their needs. Therefore, as the *conditions* are today the everyday life is full of frustration. Besides that, they miss, to a great extent, the possibility to *regulate the temperature* in each room and they find it especially hard to control the temperature of the floor heating. They do not trust the ventilation and heating system to run as it should.



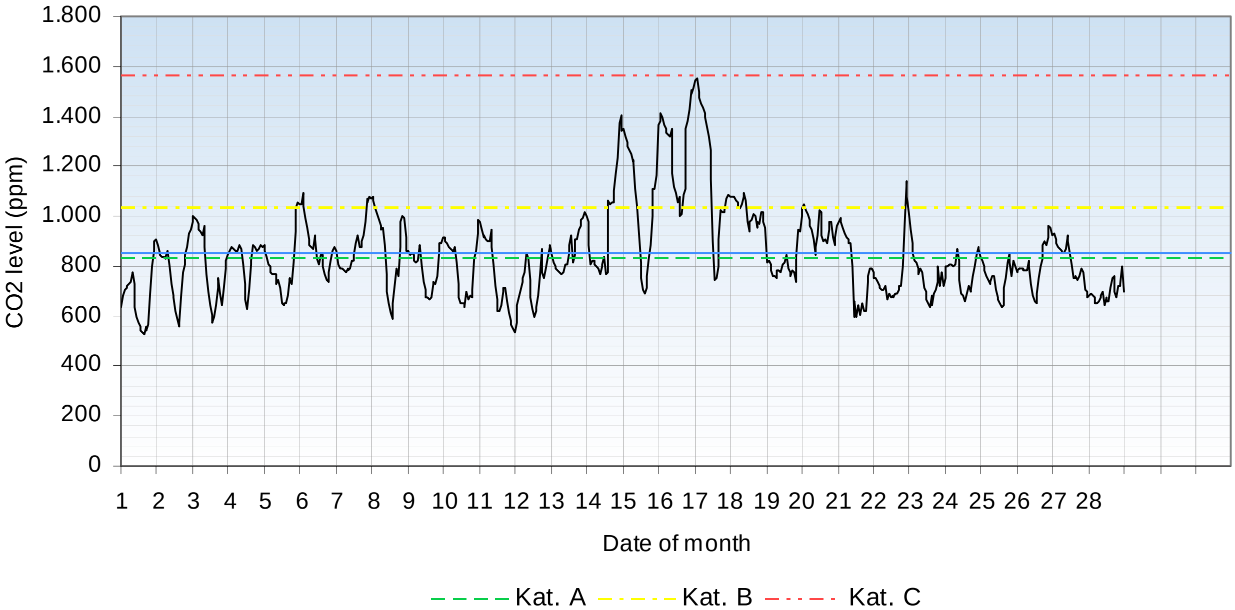


Figure 12. The figures show the measurements of the CO_2 level in June (top) and in February (bottom). The aim is to have a CO_2 level within category B – below the yellow line.

The occupants in case 8 also experience that it is too hot in the summertime. This house has no overhang of the southern orientated windows and the occupants have put up internal shading to reduce the heat gains, but they do not think it is sufficient. They also try to solve the problem by using natural ventilation through windows and doors, but as explained above they think it is designed very poorly – few opening parts and the opening parts cannot stay open by themselves. Besides that the occupants point out that the natural ventilation cannot be used when they are not at home, because you need to ventilate by using the doors and therefore there is no theft protection.

"Nothing helped; we had to go out in the garage. We put up curtains and we could not keep the doors open when we are not home, that was what the idiot of an architect said we had to do (when we complained about the conditions). Besides that the windows must be open, but it is not possible – the windows can not stay open because they are not designed to stay open. They have a small screw you have to turn and it has to be done every time ... And put alarms on and leave the window open (when you are not at home), I do not think so." (Case 8)

The life in the Comfort House is different from the life in their previous home, where they had rooms in the house where it was chilly in the summertime, but generally they experience that it is too hot most of the year in front of the southern window when the sun is shining. Therefore they have moved most of their family time into the living room, which only gets direct sunlight in the morning and therefore feels cooler. Again the everyday practices have become more difficult than they are used to.

Discussion

Comparative study of the three cases – a discussion of the changes in the occupants' everyday life in the Comfort Houses

The presentation of the results above shows that the everyday lives of the occupants in the Comfort Houses have undergone some changes during the first period of living in the houses according to the models defined previously in the paper. In the following a comparison and discussion of the result of the three cases will be presented.

Qualities and problems of the Comfort Houses

A comparison of the opinions shows that there is an overall tendency that all cases are satisfied with the architecture of the houses, especially in relation to the open plan solution which supports the family being together in the home, and satisfied with the interrelationship of the functions and rooms. Additionally, most cases mention the nice daylight in the family rooms and views from the houses. The occupants could choose between all the houses and therefore pick the house they liked the best and had the qualities they liked. However, it might illustrate that the common areas, the layout of the house and the view and daylight are the most important qualities for them and that the design teams have succeed in fulfilling the overall needs of the architecture. The problems they point out are more varied and may be more interesting to investigate. Have the problems anything to do with the fact that the houses are passive houses or are they "normal" problems which could occur in "traditional" houses as well? Two cases also mention that they would like more daylight in some rooms which are facing north. The other problems are more individual and specific for each case. The lack of storage and shelter in the outdoor areas and quality of workmanship has more to do with the design, construction and economy of the house than the passive house concept directly. This does not make the problems less important, they are simply problems which also occur in many other projects and therefore of little interest to this paper.

Transparent facades

The findings showed that the three cases had varying experiences with transparent facades to the south. One case needs to close their blinds often to feel private, another case only close them sometimes, where the last case do not care at all if anyone looks into their home. Comparing the context of the house with their experience with the transparent façade, illustrated in figure 13, it is possible that the feeling of being exposed is dependent on the context. If the house is pulled back from the street and the neighbour in front has a more opaque façade orientated to you, the need to create privacy decreases. Of course the amount of plants and trees also has an affect. All houses have limited plants in the surroundings, because it is a newly developed housing area. Nevertheless, in two of the cases the families have started to develop new everyday practices by using the blinds or curtains to create privacy. The question is whether we just have to accept those practices and "*feel a little box-like inside"* in the future, or if the privacy aspect needs to be taken into account to a greater extent when designing future passive houses. The focus has to be on both placement of the house according to neighbours and street, but also to the design of the outdoor areas with plants and trees. It can be questioned if the window areas to the south are much larger in passive houses than in "traditional" new single-family houses today. There is a general tendency to have relatively large glass facades especially facing the main outdoor areas which mostly are placed to the south or west of the house. Therefore the experiences of the occupants could be a general response to take into account when designing single-family houses in the future. Nevertheless the south orientated windows are principally a necessity to achieve passive solar heat gains to be able to fulfil the passive house criteria.

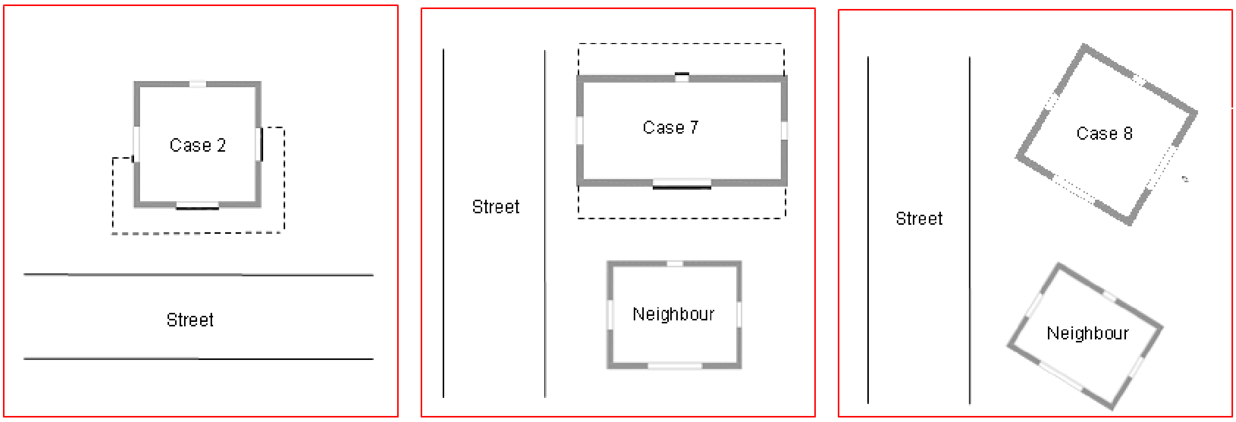


Figure 13: The diagram shows the concept of how the houses are placed in relation to the road and to each other. The windows are conceptualised by putting the windows together as one, but they fit with the right percentage of the façade. The dashed line in front of the window indicates the overhang. The overhang only shades the windows in midsummer and only at midday. It means that the morning and evening sun comes in through the windows.

Excess temperatures

Compared to the occupants' everyday life in their previous homes all cases have undergone changes. The *conditions* were different in their previous homes, because they did not have any problem with overheating. A life in a Comfort House (based on these tree cases) forces the occupants to be more aware of natural ventilation and solar shading and they need to take action to ease the problem, however they are still very dissatisfied with the thermal indoor environment. If this should be changed in future passive houses, it is necessary to look at the design and design process behind the house and focus on how to minimise the risk of overheating. It is not possible to point at one aspect that would solve the problem, it could be several and maybe in a combination. Examples could be: generally optimise the solar shading and maybe add automatic controls as seen in lots of German passive houses today. Optimise the design of the natural (and night) ventilation. Give better information to the occupants of how to live in a passive house and what consequences different behaviours have. And maybe the most important approach, which is to analyse and document the indoor environment of the design proposal through the design process with calculation and simulations to find out what initiative would fit the individual project the best both technically and architecturally.

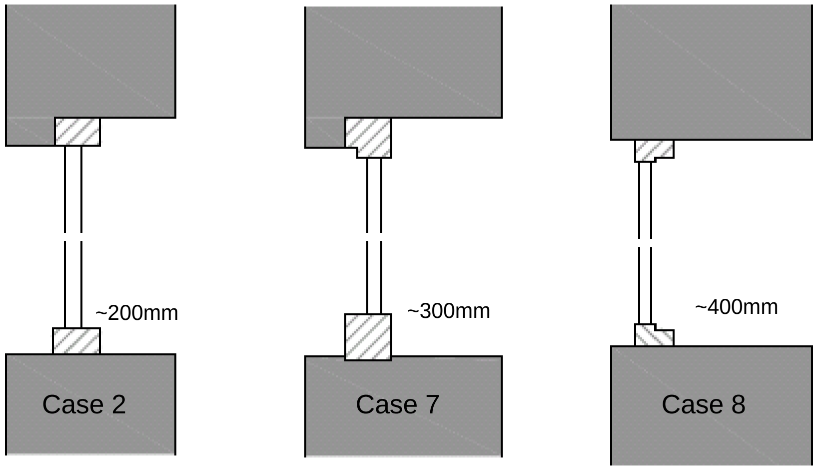


Figure 14. The illustration shows the different window solutions

Passive house windows and the wide embrasures
None of the three cases see the deeper window embrasures as a problem; in one case they actually think they are usable for other purposes, but unfortunately they do not use them because of the lack of comfort caused by too much solar heat gains. Another case has hardly noticed the deeper embrasures. These different readings can have a connection to how the window has been built into the wall (the *conditions*); in the middle, far back or aligned with the outer wall, e.g. the windows placed in the middle of the wall do not expose so much internal embrasure and therefore it does not look much wider than "normal", see figure 14. The size and placement of the windows can also have an influence on the experience of the embrasures. If the windows are put together in larger section and they are made as floor-length windows, it does not show the wide embrasures as much as smaller windows with window sills. This might illustrate the design teams' awareness of the challenge with the wider embrasures. This study shows it has resulted in satisfying solutions for the occupants. Regarding the wider frames, in the two cases where the frames are wider, they do not experience that as a problem. It could be because the occupants in the two cases have a different nationality than Danish and are maybe more used to wider frames. But it could also show that the aesthetic aspect is not as important to the occupant as it is to the architects, who prefer the slimmer look.

Ventilation habits
The three cases show three different responses to how it is to live in a house with a mechanical ventilation system. One does as they are used to, another one has developed new habits – habits that follow the way it was presumed, and finally, a case where they try to follow the idea and thoughts of the system, but it does not satisfy their needs and they supplement with natural ventilation. The latter might have something to do with the fact that three out of four occupants smoke in the house. The question is why the three cases have different experiences and habits with the ventilation systems. The controls of the systems are a little different in each house and some could be more user-friendly than the others and result in a different use. An important point could be the lack of information and "education" about how to handle the ventilation systems and the consequences of different behaviours on both the indoor environment and the energy use. All the occupants have had very limited information about the technology and the use of a passive house, for the most part they have acquired the knowledge step by step, when technicians or the owner have been in the house to install or correct something. A better introduction to the passive house and heating and ventilation system, e.g. through a manual, could have given the occupants a better understanding and thereby more trust and courage to using the ventilation system "correctly". The question also arises; can the idea behind the passive houses regarding the ventilation become a part of the Danes' everyday life? It needs to be able to, because the ventilation system with heat recovery is one of the essential aspects of minimising the energy use in buildings, therefore it is not expected to see future low energy houses constructed without it – an unavoidable *condition* of the everyday life. To create the foundation for, in some cases, a more satisfactory everyday life, an optimisation of the *conditions* is necessary. Therefore is it

important to focus on the user-friendliness and deliver information about the systems to the users. Or perhaps the systems have to be more automatic? But is it alright to turn the occupants into passive inhabitants with no knowledge? This paper cannot answer these questions, but the situation possibly has to be evaluated in each case. It is foreseeable that some groups of occupants or landlords would prefer a more automatic system in e.g. social housing, where others like e.g. privately-owned single family houses prefer more manual control.

Regulation of the temperature
All cases would like to have a greater possibility to regulate the temperature individually in every room and two cases actually do not trust the system to deliver the heat that it should. If this is compared to the situation they are used to, where all had radiator heating in each room, it shows that their freedom has been taken away from them and now they have to rely on the technical service system. Previously, they just turned up the radiator if they were cold, therefore the situation today has given the occupants more trouble in their everyday life than they are used to. Now they either do not know what to do and put clothes on, or call a plumber. Is this how people should live in a passive house in the future? Even taking into account the initial problems with the heating in case 2, the possibility of regulating the temperature in the individual room was not available. This shows that the original idea about heating up the house with ventilation air regulated from the central aggregate is too restricting for the occupants. Therefore we might have to go back to some solutions that the occupants are already familiar with e.g. heating up with radiators or floor heating with individual temperature controls. This tendency is also seen in German passive houses today even though the original ideas of saving the expenses in the extra installation disappears (Personal communication with Troels Kildemoes from the company “Ellehauge og Kildemoes”).

Comparative study between the Comfort Houses and other passive houses
Because this study only is based on three cases it can only give us a hint of how the occupants of a Danish passive house experience the architecture and live their everyday life in the houses. Additionally, it can be discussed if the time the occupants have lived in the houses before the second interview has been long enough (between six to ten months). To strengthen the conclusion some of the results are compared with the results of the research projects presented in the introduction. It shows that a number of similarities occur.

In Kronsberg they were satisfied with the thermal environment in the summer, but 40% of the housing units have invested in additional shading devices and many supplement with night ventilation to reach a satisfactory indoor environment. It is a similar situation in Lindås Park, where they also felt too hot in the summer. About half of them have installed external shading and supplement with natural ventilation. In the Comfort Houses they also feel too hot. All three cases have installed internal shading, but it is not as efficient as the external. Besides that they supplement with natural ventilation, but here the openings in some cases are made in a way that they cannot be left open when the occupants are not at home. As the situation is today the occupants just have to live with the excess temperatures, but maybe they might install external shading or air conditioning as two cases expressed could be a possibility. In Kronsberg and Lindås Park some occupants could not accept living like that and invested in additional shading. It tells us that external shading is an aspect that needs to be improved and needs to have a greater focus when designing future houses.

The ventilation routines, regarding the air quality in the German and Swedish studies, show results as diverse as the case of the Comfort Houses. In Kronsberg they had no problem adapting to the systems, in Lindås Park some occupants became increasingly confident, where others were afraid of the technology. This can be very dependent on the kind of system and the user-friendliness of the technology and finally depends on the information, manuals or “education” they have received about heating and ventilation systems. It becomes clear in all the studies that information about the passive house and the technical service systems is very important. This supports the discussion of how the experience with the ventilation system could have been more positive in the Comfort Houses if they have received more information about it.

The control of the thermal indoor environment in the winter period depends greatly on the ventilation system and the solar heat gains. Both the study of the Comfort Houses and the other studies show that you need to get used to not having the possibility to regulate the temperature in each room and most occupants experience uneven temperature in the rooms because of solar heat gains; nevertheless some occupants in Lindås Park think it does not matter because they can light candles and it will heat up. It can be discussed if that is a sustainable solution in the long run. As discussed above under “Comparative study of the three cases” – “Regulation of the temperature”, maybe we need to go back to heating up the houses with more controllable technical service systems e.g. radiator or similar that people already know. Can we accept living in a house were there are uneven temperatures throughout the house? Is that comfortable? If we want to sell the houses as *comfortable* houses and not just as *passive low energy* houses, it is believed that this is not acceptable.

Regarding the time aspect between the two interviews of the occupants, an extra interview after maybe one more year in the houses would show if they still have the same everyday practices or if they developed new practices. Topics, in which a longer period of time in the houses could have affected the results, could be in relation to the ventilation and heating practices. Maybe the occupants who were afraid of the heating and ventilation systems have become more knowledgeable and gained the courage to use the system after more time in the house. The other everyday models are more dependent on the architectural and structural solutions and unless the occupants are changing them, their experiences and practices would possibly be unchanged. But as the above comparison shows is there a fine agreement between the results. Therefore it can be stated that the period of living in the house before the interviews has not been too short. And the results have given a good idea of what it is like living in a passive house perhaps not only in Denmark, but in general.

Reflection on methodology

The methodology of using models of the everyday life within the frame of Birthe Bech-Jørgensen´s double perspective gave clarity to the research – clarity to understand how physical environment of the Comfort Houses with all its facets affect our lives. The double perspective shows how the *conditions* and the way people *manage* those *conditions* are greatly interconnected. By changing just few elements of the *conditions* the way the occupants experience or behave can change dramatically – from a positive experience to a frustrating experience. The methodology helps to break down the investigations into understandable and less complex parts; the models, the *conditions* and the *management* of those, which again together as a unity forms an understanding of how it is to live and act in Comfort Houses. The behaviours described in this work is not just pure behaviour, but actions that affect the everyday life and can in some situations change the everyday life so much that it becomes an unwanted part of life. Without this perspective the models would be plain hypothesis, which might not have led to discussions about the interconnectedness between the *conditions* and the *management* of those and how those affect the everyday life. The hypothesis would give initial hunches about relationships and would have been confirmed or disconfirmed, but do not as such prepare the ground for further discussion and understanding of the interconnectedness between people and Comfort House.

In future work if more cases should be implemented in the research material the methodology of field work by observations would be considered implemented. It could support the interviews with an extra dimension e.g. register other behaviours than defined in the models, register if the occupants actually are doing what they say they are going, get a more profound understanding of the occupant life and their logics etc. This requires a different planning and timeframe than the method of qualitative focus group interviews.

Conclusion

This paper has discussed how the everyday life of the occupant in a Comfort House can expect to be found within the everyday models defined in this study. Some of the expected changes in the everyday practices are confirmed, some repudiated, and some are additionally verified with similar studies. The changes that are important to emphasise are:

- Curtains and/or blinds have become a part of the everyday practice of creating privacy in some of the cases.

- The occupants needed to develop an awareness of the thermal environment and therefore curtains or blinds, plus natural ventilation are a permanent part of the everyday practices in the summer to reduce undesirable high temperatures.
- Some occupants have become worried about the air quality and do not trust the mechanical ventilation system and one case shows that it is possible to be very satisfied with the new system and functionality of it.
- The freedom of controlling the temperature in the houses has been restricted – a situation they just have to accept in their everyday life in these cases.

Additionally, the Comfort Houses' ability to fulfil the occupant's needs has also been outlined. Generally the houses fulfil the need of the occupant. Few problems are a result of the passive house concept, which is worth being aware of when designing future passive houses. Firstly, the large windows to the south can create discomfort, because of the lack of privacy due to people passing by. Secondly, single rooms to the north could have had more daylight and improvement regarding the nice view to the north. This shows that it is important that the house is designed to the site and the context, were both pros and cons of the site, like looks from people passing by and the view, are taken into account.

If the passive house is to become a success in Denmark and maybe also in other countries, it is important to be aware of the above mentioned everyday life practices in a passive house. The future occupants or owners of a passive house need to be aware of the possible changes to their everyday lives. If this is not acceptable, the conditions need to be changed and the way the occupants manage those conditions will result in a different everyday life; cf. the double perspective of Birth Bech-Jørgensen. Through the discussion different suggestions as to how to change the conditions are presented. Maybe we have to go back to some of the technologies we already know or maybe find some compromises, so it is possible to design passive houses that fulfil the occupants' needs and allow them to have freedom and control of the house and still fulfil the energy demands of the future. Therefore information and knowledge about both the technologies and the way to act in a passive house (or any other low energy house) is important for this concept to be a success both for the occupant and the environment.

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Publication 3

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Evaluation of the Indoor Environment in the Comfort Houses - Qualitative and Quantitative Approaches

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Abstract: *Today the build environment accounts for about 40 % of the energy consumption in the EU and it is continuing to increase. It is a result of an effort to give the building users an optimum indoor environment. New buildings and renovation projects need to improve the energy performance and in a process of doing so, it is important to maintain a good and healthy indoor environment and not on the expense of it. One way of saving energy is to build passive houses. This paper presents the result of a case study of some of the first certified passive houses in Denmark, called the Comfort Houses. The paper evaluates the indoor environment through both quantitative measurements in the houses and qualitative interviews with the occupants about their experiences of the indoor environment. Two set of knowledge which together gives a more complete and holistic picture of the indoor environment. The study shows that we need an accentuated focus on the goal to aim for in the design process, the documentation of the designs and on the occupant's life and behaviour. Finally it is important to "educate" the occupants to live "correct" to achieve comfortable indoor environment.*

Key words: *Indoor environment, housing, passive houses, qualitative, quantitative*

Introduction

Today the build environment accounts for about 40 % of the energy consumption in the EU and it is continuing to increase [1]. It is the consequence of an effort to give the building users a best possible indoor environment by good ventilation, comfortable temperatures and sufficient light. The building industry in Denmark and the rest of Europe is facing challenges in fulfilling the EU directive of 2002 [1]. New buildings and renovation projects need to improve the energy performance and in the process of doing so, it must *not* be on the expense of the indoor environment.

One way of saving energy is to build houses according to the German Passive House Standard [2]. A passive house is usually very well insulated, very air tight, orientated to the sun and has a ventilation system with very efficient heat recovery, resulting in a low energy use. The concept is now very well acknowledged internationally and many countries are constructing houses that fulfil the passive house standard defined by the Passive House Institute in Darmstadt, Germany [2].

This paper presents the result of a case study of some of the first certified passive houses in Denmark, called the Comfort Houses [3, 4]. The Comfort Houses consists of ten different single-family houses according to size, materials, style, construction, installations, equipment etc. Eight of the houses are today certified passive houses and are presented in figure 1. Besides fulfilling the passive house criteria the development of the Comfort Houses also have great focus on comfort. The vision of the initiators was to make people aware that passive houses also mean comfortable houses. The initiators had two reasons for that. Firstly they wanted to spread the knowledge of the positive consequences of constructing passive houses. You automatically fulfil some comfort aspects like warm surface temperatures. You also avoid draught because of the very well insulated and air tight building envelope, and still have good air quality because of the mechanical ventilation system. Secondly it was believed that the term comfort appealed more to the future house owners than the terms passive houses and low energy houses. It is believed that if this housing type should become a success in the future, the building designs should be comfortable – live up to a generally satisfactory indoor environment. At the same time is it believed that it is necessary to create buildings or homes that are complete and holistic solutions, where architecture and more functional and qualitative requirements regarding the indoor environment also needs to be integrated – like user-friendliness and robust solutions that can tolerate different user behaviour. It is important to know how the houses perform with occupants, because their understanding and behaviour is crucial to be able to achieve a comfortable indoor environment.

Figure 1. The illustration shows the eight certified passive houses in the project of the ComfortHouses.

The purpose of this study is therefore to evaluate the indoor environment through both quantitative measurements in the houses and qualitative interviews with the occupants about their experiences of the indoor environment in the house: To what extent do the Comfort Houses live up to a comfortable indoor environment? How do the occupants of the Comfort Houses experience the indoor environment and the possible adjustments of it? And how does the experiences relate to the measured indoor environment?

The quantitative measurements are a part of a demonstration project: "Demonstration of energy use and indoor environment in 10 Danish passive houses" [5] which is focusing on energy use, thermal comfort and indoor air quality, daylight conditions and acoustical climate. This paper focuses on the indoor environment part and leaves out the topic of energy use. The results will be based on three of the eight houses, as the remaining houses were unoccupied at the time of this evaluation. The qualitative interviews are part of at bigger research project with more research topics, where each house and the respective occupants represent a case. Despite this it has not been possible to include all cases in all studies; the same case numbers are retained throughout the studies to maintain continuity across all works. This also gives the reader the opportunity to make comparative study across study fields by reading other publications within this research project, e.g. "*Interview Report about the Design Processes behind the ´Comfort Houses´"* [6]. This study focuses on case 2, 7 and 8.

Methods

As mentioned in the introduction the purpose of this study is to evaluate the indoor environment both through quantitative measurements and qualitative interviews in the Comfort Houses. Both approaches are taken because they give two different kind of knowledge. Knowledge that together give a more complete and holistic picture of the indoor environment since one set of results can be further explained by the other. In the following this approach of *mixed methods* will be outlined and followed up with a more detailed explanation of the qualitative and quantitative methods.

Mixed methods

The amount of cases, where *mixed methods* – or research that integrates qualitative and quantitative research have been used, has increased since the 80´s [7]. Today you find more publications about the subject e.g. Journal of Mixed Methods Research and more general publications about mixed method in social research e.g. Alan Bryman [7], Abbas Tashakkori and Chales Teddlie [8]. According to research done by Alan Bryman the argument of using mixed methods can be different. He developed different categories of mixed methods approaches e.g. *Triangulation, Completeness, Explanation, Credibility, Illustration, Utility, Enhancement* etc., were research work often can cover more categories [7, 9]. The purpose of this publication is not to outline the meaning of all approaches, but just to illustrate that the argumentation of combining both qualitative and quantitative research can be different. To answer the research question of this study, mixed methods are essential. Even though the publications mentioned above focus on mixed methods in social research e.g. questionnaires and/or statistics vs. interviews and/or ethnography. It is believed that mixed methods terminology also covers qualitative social research methods and empirical analytical methods of natural science. Regarding Brymans terminology the approach in this study fit with the following categories:

Completeness: refer to the notion that the researcher can bring together a more comprehensive account of the area of enquiry in which he or she is interested if both quantitative and qualitative research are employed.

Illustration: refer to the use of qualitative data to illustrate quantitative findings, often referred to as putting "meat on the bones" of "dry" quantitative findings.

Utility: or improving the usefulness of findings – refer to a suggestion, which is more likely to be prominent among articles with an applied focus, that combining the two approaches will be more useful to practitioners and others. [7]

The combination of qualitative and quantitative methods can give more nuanced result of the investigated issues. An example could be: Measurements of the indoor temperature in a room show too low temperatures 25% of the time. The measurement can not give the answers to *why* the temperatures are too low - Unless we for example have observed that the window has been open, and then suggest that to be the reason. The observation and the measurements only explain *how* the situation is, but cannot tell *why* e.g. the window was open. The researches can have some suggestions, but they are based on his/hers previous experiences and not based on empirical scientific work. If the researcher needs to know *why*, he/she has to step into another approach e.g. involving the occupants of the room that might give the explanation of the open window. This combination of knowledge will give a more holistic understanding of how to achieve comfortable indoor environments in practise where user behaviour and user understandings are taken into account. The qualitative interviews and quantitative measurements are juxtaposed in a comparative study.

An example of where qualitative social research methods and empirical analytical methods of natural science have been combined, is the work in the research project "Indoor Environment and Quality of Life" at the University of Southern Denmark. A part of the project is to investigate people's notion of comfort [10]. This is done by conducting ethnographical field studies in people's life parallel with collecting measurements of comfort parameters like temperature, light, humidity and CO_2 levels. The study shows that the occupants' behaviour not necessarily reflect the building standards' notion of comfort. The study therefore suggests: *"The concept of comfort has to be expanded to include not only physical factors, but also, psychological, behavioural and mundane, situational ones"* [10]. The study could not have come to this statement with only one perspective – it was necessary to use both qualitative and quantitative methods.

Quantitative Measurements of the Indoor Environment

In the tender document, send out for the Comfort Houses, specific demands for the indoor environment were missing even though the houses were named the "Comfort" Houses. In the following the demands for the indoor environmental parameters used in the quantitative measurements in the houses are presented.

A distinction is made between continuous measurements, which are made every fifth minute throughout the measurement period (three years), and spot measurements, which are made during visits in the houses. The continuous measurements are: temperature, CO_2, and relative humidity (RH) - in a bedroom, master bedroom (only in some cases), living room, kitchen and bathroom. The focus will be on the living room and bedroom. In some analysis other rooms are used to illustrate similarities or differences. The bathroom measurements will not be touch upon in this paper. Spot measurements are: Daylight factors in the living room and reverberation time and noise from the ventilation system in living-kitchen area.

Thermal comfort and indoor air quality

The thermal comfort and indoor air quality is evaluated by using the guidelines set out in CR 1752 [11]. The CR 1752 is developed for office buildings and can therefore only be used as an indicator because firstly there are no standard or guideline for indoor environment in housing and secondly the requirement to the indoor environment of the occupants is very individual. This underlines even more the necessity to combine the measurements with qualitative interviews. As mentioned did the tender document of the Comfort Houses not define any specific demands to the indoor environment of the house, but since the houses are marketed as *comfort houses*, it is estimated that the houses should meet category B in CR 1752 as a minimum. Table 1 illustrates the requirement for the thermal indoor climate in different categories. Maximum average air speed has not been controlled during the measurements, since it is not considered as a problem.

Regarding the atmospheric indoor environment the CO_2 level in the house must not exceed 660 ppm above the outdoor level (outdoor average is 370 ppm), ie. 1030 ppm, to meet cat. B confers CR1752 [11]. Regarding relative humidity (RH) the same standard recommends a level between 30% and 70%. A RH lower than 30% will result in discomfort in the form of dry air, static electricity and desiccated mucosa. The upper limit of 70% should be respected to avoid problems with moisture and mould in the dwelling.

Table 1. Demands for temperatures and average air speeds for category A, B and C [11]. In this study a comfortable indoor environment is fulfilled at category B.

Activity level	[met]		1,2		
Category			A	B	C
Operative temperature	[°C]	Summer	24,5 ± 1,0	24,5 ± 1,5	24,5 ± 2,5
		Winter	22,0 ± 1,0	22,0 ± 2,0	22,0 ± 3,0
Maximum average air speed	[m/s]	Summer	0,18	0,22	0,25
		Winter	0,15	0,18	0,21

Daylight

Daylight is evaluated by the demands in the Danish building regulations paragraph 6.5.2 , which says: *"Working areas, occupiable rooms in institutions, teaching rooms, dining areas and habitable rooms must have sufficient daylight for the rooms to be well lit. Windows must be made, located and, where appropriate, screened such that sunlight through them does not cause overheating in the rooms, and such that nuisance from direct solar heat gain is avoided."* [12]

In evaluating the results a daylight factor of 2% will be used as a minimum limit of the daylight factor, but if the situation must be assessed as good daylight conditions, this should be achieved all the way through the room and not only in areas that can be considered as workplaces. In this way the depth of room is also included in the measurement, since deep rooms should have larger or higher located window area than narrow spaces. The measurement method follows the instructions in the SBI instruction 219 [13]. The daylight factor is only measured in the common rooms.

Noise

The evaluation of the measurements of noise from the ventilation system and the reverberation times in the living room have been based on DS490 [14], because BR08 [12] refers to the function requirements in this standard. Even though the demands in BR08 are minimum class C, the demand in this evaluation is set to class B, because of the formulation of the demands in the tender document:

"Consideration must be given to the building's sonic capabilities of the project, so the house appears as a comfortable house to live in. Here should especially the reverberation be taking into account. All construction joints, installations and penetrations must also be soundproofed" (translated from Danish).

This formulation equals the formulation of class B in DS490 [14], as referred to in the building regulations (BR08) [12]. It means that the noise from the ventilations system must not exceed 25DB on "normal" operation and the reverberations time must not be longer than 0,6 second in a furnished room [14]. All measurements are done in the living-dinning room, but without furniture, because the occupants have not moved in at the time of measuring. This will of course be taken into account when discussing the result.

Qualitative Interview about the Indoor Environment

The qualitative interviews are conducted as semi-structured interviews, which mean that the interviewer has a general question guide, in which he/she is able to change the order of questions or ask additional questions to what may have significance for the study [15]. The qualitative research interview is suitable when the goal is to understand another person or group of persons' experiences of their own life-world. The qualitative interviews differ from the quantitative interviews, such as questionnaires, by being more flexible, because the interviewer has the opportunity to ask new questions, following up on responses. In a conversation new insights often occur, which may have relevance for the research, which the qualitative research interview allows [7]. Results from the qualitative interviews will be condensed reproductions and quotes of the interviews. Two of the three interviews were conducted in Danish; it means that the quotes are translations from Danish to English. The translation is done as close as possible to the original statement, but small inaccuracies can occur.

The qualitative interviews study consists of two interviews were the first is about the experience of indoor environment in their previous home and the second interview is about the experience of the indoor environment in the Comfort Houses after the first summer and winter in the house. The first interview is not directly a part of the results, but is conducted to have a reference according to what conditions the occupants are used to, and maybe thereby giving a better understanding of their experiences in the Comfort Houses.

The interviews were conducted parallel with the logging of the continuous measurements. It means that none of the measurement were analysed before the design of the interview guide finished. The question guide design is therefore more general. The topics of the interview guide were related to the topics of the measurements; like thermal indoor environment, air quality, noise and daylight, which was very concrete and direct questions e.g. *"Can you stay warm in the house?", "What do you think of* *the daylight conditions?"* But there were also "softer" questions, which was based on description of experiences like: *"Can you tell me about one or more situations were you were dissatisfied with the indoor environment?"* Or *"If you are cold what do you then do?"* Questions like that give a more comprehensive analysis of the measured data by linking to the occupants' life in the house. That can give understandings of the indoor environment which are more applicable to practise.

The two approaches described above, will form the basis for the data collection. And the two sets of knowledge they produce will be analysed in a comparative study. It results in a more holistic understanding of the notion of comfort in the Comfort Houses both from the social and the technical point of view.

Results

In the following the results will be presented in a comparative study between the quantitative and qualitative results from case 2, 7 and 8, which will be subdivided in the indoor environmental topics presented in previous section.

The houses have in some periods been unoccupied which means that the concerned data have been left out of the analysis. It means some of the charts in the following will contain values of zero.

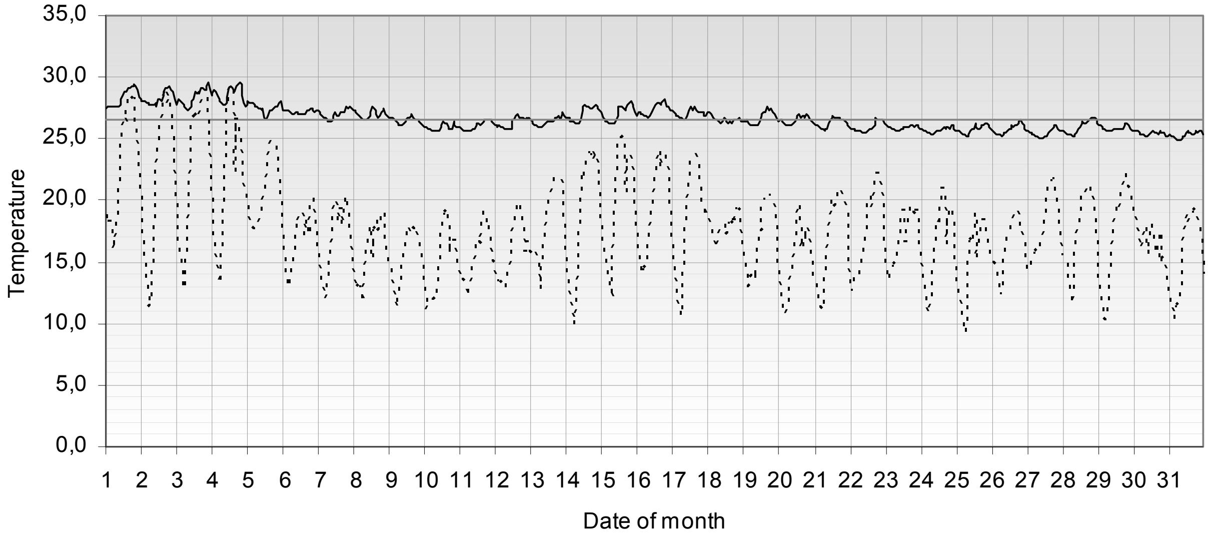


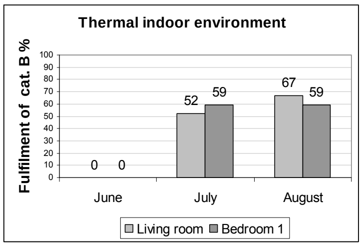
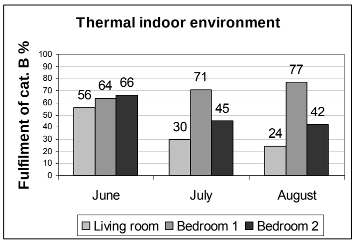
Figure 2: The full line illustrate the indoor temperature in the living room in case 7 in July 2009, the dashed line is the outdoor temperature. The indoor temperature do not drop below 25C and the average temperature is 26,6C (the thicker gray line).

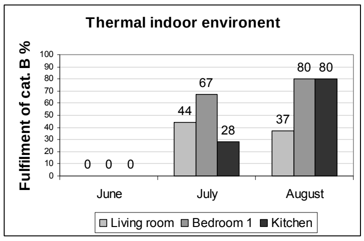
Thermal indoor environment

The results of the thermal indoor environment are divided in summer and winter situations. Firstly the summer situation is presented, table 2.

The thermal indoor environment in the summer is poorly fulfilled in all three cases, especially in the living rooms. The measurements show that there is a tendency of excess temperatures and case 7 decidedly does not meet the comfort requirements. One explanation could be that the summer by-pass was not used. It is exemplified in figure 2 showing the indoor temperatures in the living room in July. The occupants in all three cases confirm in the interviews that the indoor environment is too hot in the summer and that they tried to solve the problem by installing blinds and using natural ventilation.

Table 2: The thermal indoor environment in the summer period – June, July and August.

<table>
<tr><th></th><th>Case 2</th><th>Case 7</th><th>Case 8</th></tr>
<tr><td>Measurements</td>
<td>
</td>
<td>

Comments: Very high temperatures (temp.). Average temp. in the period is approx. 26°C.</td>
<td>
</td></tr>
<tr><td>Interviews</td>
<td>The occupants experience that it is too hot in the summer period in the house. They have installed internal blinds and try to further solve it with natural ventilation (vent.) and by wearing very light cloths.</td>
<td>The occupants experience that it is very hot inside. They try to solve the problem with natural vent., but it only helps a little, therefore they have thought of installing air-conditioning. They experience that heat moves around with the sun, it means it is very hot in the bedroom and the children's room when they sleep. They do not want to leave windows open in the daughter's room when she is sleeping, due to safety reasons.</td>
<td>The occupants experience that it is too hot in the house. They have installed internal curtains, but do not think it helps. The natural vent. does not work sufficiently either. The windows have trouble staying open because of the lock mechanism. Additionally, windows are not left open the planned amount of hours due to theft protection. When nothing helps, the occupants go out in the garage.</td></tr>
</table>

In case 7 the occupants' descriptions of their behaviour (they rarely open windows in the children room because of the safety when she is sleeping) might show that the occupants' behaviour and psychological experiences have an influence on the resulting thermal comfort of the house. In this case the safety of the daughter is more important than the thermal comfort in her room, so they do not open the window even though they feel the need of it. Maybe the house is designed well regarding the thermal indoor environment – confer the standards, but then a different operation by the occupants result in a worse indoor environment. This might also be the situation in the other two cases. Maybe the natural ventilation in the houses was designed to deliver a sufficient amount of air to fulfil the thermal indoor environmental requirements in summer, but if the designs do not fit with the psychological or social behaviour of the occupants the attempt will fail. On the other hand, if the natural ventilation should work sufficiently, the design also needs to be functional and manageable for the occupants within their practices:

"…we could not keep the doors open when we are not home. That was what the idiot of an architect said we had to do (when we complained about the thermal conditions). Additionally, the windows must be open, but it is not possible – the windows can not stay open because they are not designed to stay open. They have a small screw you have to screw on and you have to do it every time ... And put the alarm on and leave the window open (when you are not at home), I do not think so." (Case 8)

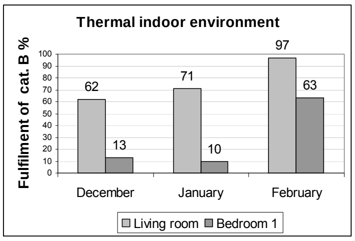
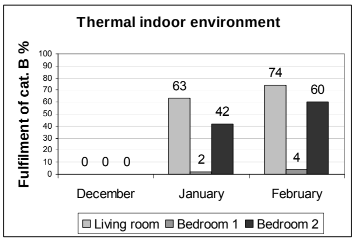
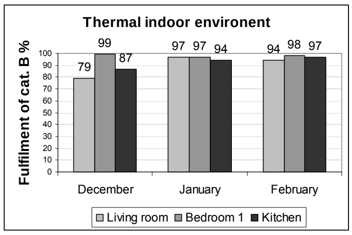
Based on the above quote, the windows should be designed in a way that they can stay open when the occupants are not at home, without compromising safety. Or on the other hand, the dimensioning of the design needs to take into account that the natural ventilation only functions during occupancy, which mostly are after four o' clock in the afternoon in single-family homes.

Furthermore, the interviews also reveal that the occupants' misunderstandings of the concept of natural ventilation can limit the efficiency of the system:

"We open the window up there (skylight). And that's another good reason why the house needs to have overpressure (confer previous interview sections in which the occupant express a feeling of negative pressure in the house), then when you open something, the air blows outwards. Now the skylight only takes in air, but do not remove anything" (Case 8).

The design idea of this house is to have a stack effect and use the skylight as an outlet. But the above quote shows that the occupant has mixed understandings of the ventilation strategies. Firstly he believes that a house always should have overpressure, but ideally it should be a balanced system. If any, there should be a little negative pressure in the house, which will minimise the risk of moisture to get into the constructions. Secondly he has not understood the principal of stack ventilation. You need to open lower part for supply air and use upper part, the skylight in this case, for outlet. The explanation by the occupant in the above quote shows that he expect to ventilate the house only by opening the skylight, which is not possible to the extend that is necessary in this situation. It shows that theory and practice not always follows. The occupants have to know how to handle the system or strategy to perform "correct". It is believed that both the combination of "wrong" occupant behaviour and poor design is responsible for the lack of thermal comfort in the summer in these three cases. The latter is also discussed in previous work about the design process of the Comfort Houses [16]. The study shows among others that the indoor environment only has been documented through the average values of excess temperature found from the energy calculations tool, which is based on mean monthly values. It is believed that an hour by hour dynamic simulation, or at least a simple check of the 24-hour-maximum temperature for critical rooms, to a greater extend would have revealed risks of overheating.

Table 3: The thermal indoor environment in the winter period – December, January and February.

	Case 2	**Case 7**	**Case 8**
Measurements	 Comments: The heating problem in the living room was resolved in January 2010 with an electric heater of 500W (temporarily).	 Comments: In January and February in the early morning the temp. are just below 20°C, see figure 3.	 Comments: The technical installations were adjusted in January.
Interviews	The occupants struggle to stay warm when it is overcast. The temp. is often down to 17°C, so they have to wear skiing underwear and warm socks. After installing a radiator (temporary) and after they were informed not to naturally ventilate in the heating season, they did not experience any problems with staying warm. They think it is frustration not to be able to control the temperature.	The occupants think it is a little cold and they cannot get more than 20°C in the house when there is overcast. It's too cold to walk around in a T-shirt as they are used to (not standard cloths in wintertime according to standards). They think it is nice when the sun is shining, then the temp. increase 2-3°C. They experience different temp. in the different rooms when the sun is shining. Especially the daughter's room (not measured) was colder than the master bedroom (bedroom 2).	In the beginning the occupants had 19-21°C, which they thought was too cold, but after the inspection of the system, the temperature came up to 23°C. The occupants miss a better management of the thermal indoor climate – they experience different temp.

Regarding the thermal indoor environment in the winter period, occupants in all three cases think it is too cold in the house. It can partly be verified by the measurement during the winter period, see table 3 – partly because case 8 has fulfilled category B over 90% of the time in most rooms and months, which is evaluated to be acceptable, because a fulfilment of category B 100% is not realistic. The dissatisfaction from the occupants in case 8 can both be explained by the low temperatures in one week in December (figure 4) and the wish of 23°C from the occupants. Mostly the temperatures have been between 20 and 22°C.

In case 2 and 8 technical adjustments in January have resulted in a significantly better thermal indoor environment both measured and experienced. Especially in case 2 the percentages of time fulfilling category B increase significantly, but the bedroom still only fulfil category B 63% of the time in February. In case 8 on the other hand the changes mostly shows in the living room. The bedroom and kitchen fulfil category B fairly well in all months. The causal explanations for the need of adjustments in the two cases are different. In one case it can be explained by poor design-related choices and in the other case it is because of technical errors when installing the systems. They will not be discussed in further detail in this paper. Case 7 contacted the plumber to know if they could raise the temperature on the system and the response was that he believed it was possible. However, this study cannot tell how it turned out. The low temperatures from the 1st to the 3rd of January in case 7 can be explained by the family being on holiday during New Years. It shows that the system needs the internal heat gains to have a "sufficient" indoor temperature, see figure 3. Additionally, the reason for temperatures below 20°C can be because the house has fewer occupants than expected and therefore has a lower internal gain than estimated in the calculations.

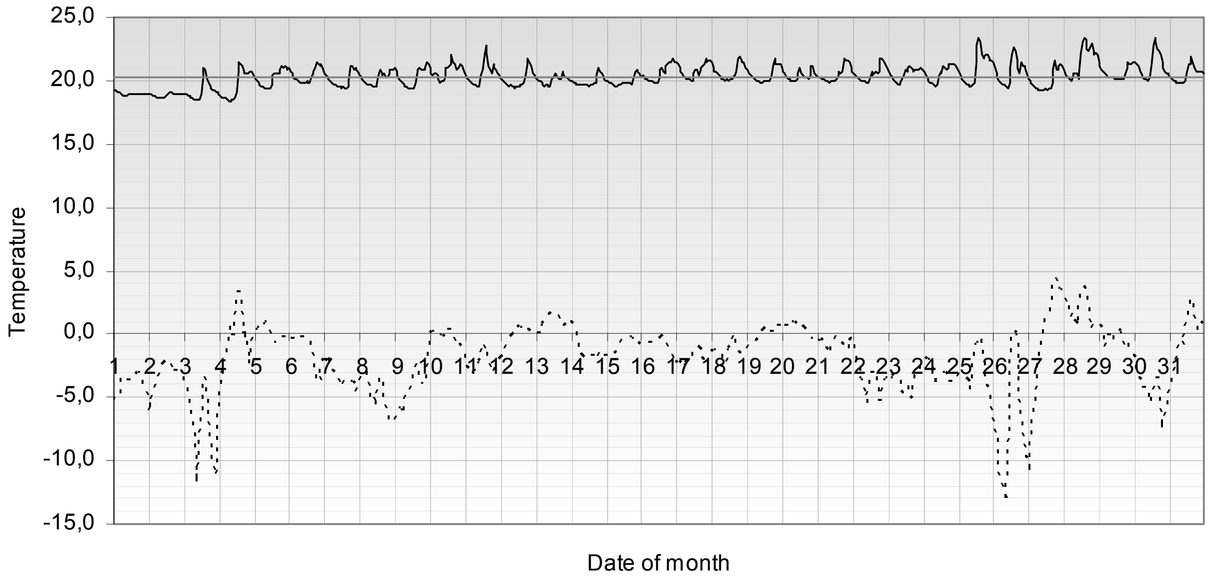


Figure 3. The full line shows the indoor temperature in January in the living room in case 7 and the dashed line shows the outdoor temperature. The indoor temperature curve shows that the temperature most mornings are a little below 20°C.

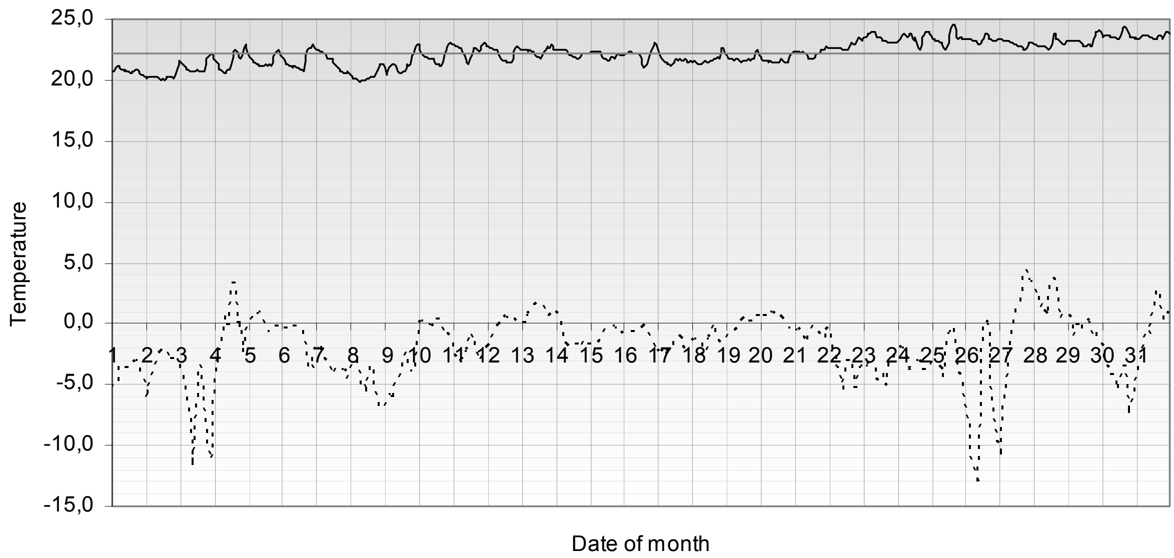


Figure 4. The full line shows the indoor temperature in January in the living room in case 8 and the dashed line shows the outdoor temperature. It shows that the indoor temperatures mainly are above 20°C, but a few days are between 19 and 20°C, in periods where the outdoor temperature drops below -5°C.It can be because the system has reached its capacity with the amount of internal gains present. Maybe the internal gains was larger the 26th because the indoor temperature is higher even though the outdoor temperature is below -10°C.

The charts in table 3 show significant differences in fulfilling category B in the different rooms in each case. The causal explanations of this phenomenon might be equivocal. Firstly the occupants describe in both case 2 and 7 that the extra bedroom is not used everyday. It might result in closing the doors to the rooms and the internal heat gains from e.g. equipment and people transport poorly to the room. Another explanation could be the lack of considering different transmission losses from different rooms and/or the lack of solar heat gains because of the orientation of the windows when dimensioning the ventilation system. Or finally the actual internal heat gains are lower than the theoretical ones used in the calculations in the planning phase. The occupants confirmed the experience of different temperatures in the different rooms. Two of the cases express a direct desire to regulate the temperature individually in the rooms, which in current state is not possible because the houses are heated up by the ventilation air and the temperature is controlled in the ventilation unit and not in each room. Additionally the occupants do not feel they can control the system, which means they are made passive instead of active participants. It is exemplified in the two following quotes:

Occupant case 2: *"It's just frustrating that you do not have anything to say about it. And none of us could come into the system (the control panel of the ventilation system)."* Interviewer: *"Do you want it to be more user-friendly, a more simple system to control?"* Occupant case 2: *"Yes, exactly."* (Case 2)

"The ventilation system lives its own life ... We want a flat screen monitor down here (first floor), and for example choose the bathroom - 23 degrees (snaps the fingers) and then we will have 23 degrees ... I have thought of writing to them (the designers of the ventilations system) if they have been `sleeping´ because it is not the way to design a ventilation system today. It's uncontrollable, it does not work and it's bad." (Occupant, case 8)

As an addition to the above results some might argue that the current winter 2009/2010 was colder than usual, which is correct but still only few night temperatures was lower than the winter design temperature of -12 degrees [17], see figure 5. Therefore the systems in theory should have the necessary capacity to be able to perform according to the conditions.

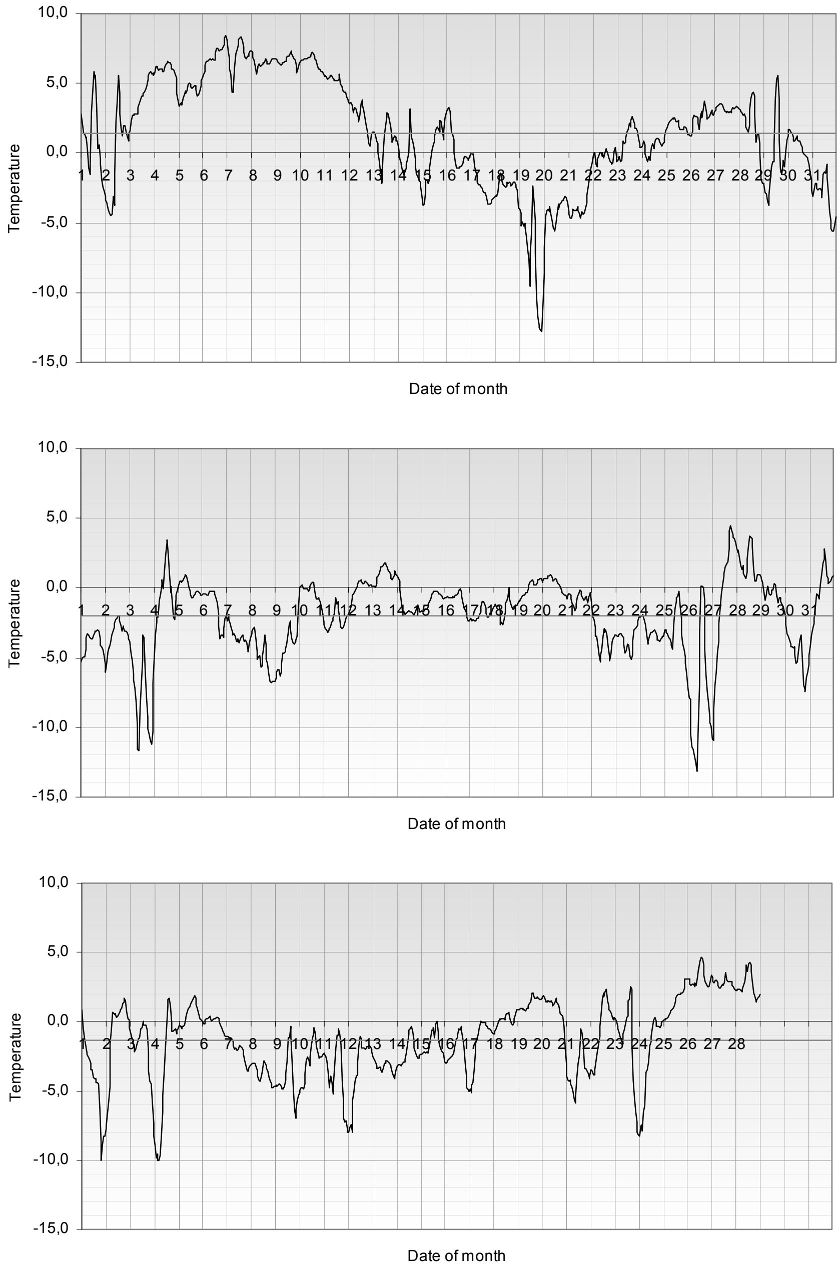


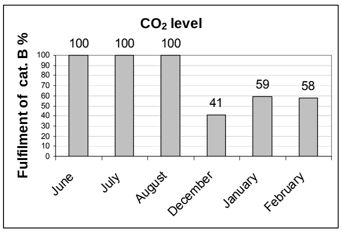
Figure 5. The outdoor temperatures in winter 2009/2010 in Vejle, Denmark. From top December, January and February.

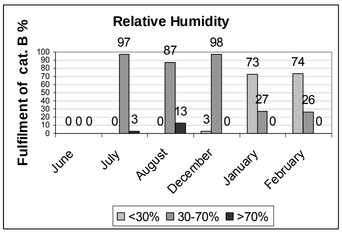
Indoor Air Quality

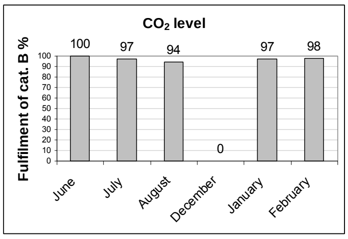
The following result of the atmospheric indoor environment focus on the living rooms and leave out the bedrooms and kitchens, because the measurements of the living rooms and bedrooms follow fairly well and because not all bedrooms was measured because of privacy issues. The measurement in the kitchen deviates from the living room in some cases which possibly is because of the cooking.

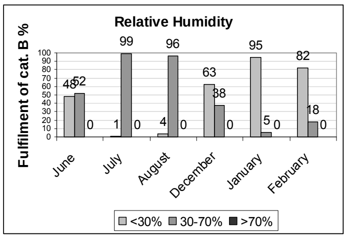
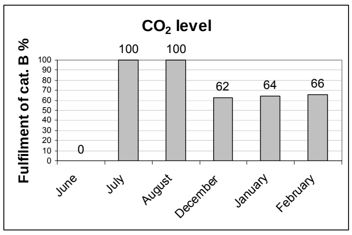
The charts in table 4 show that there are no problems with the CO_2 levels in the summer period, whereas the fulfilment of the CO_2 levels in the winter decreases in case 2 and 8. This variation between summer and winter shows a normal pattern, which is due to the fact, that the house is more open during the summer period because of open windows and doors. The occupants in case 2 and 7 generally feel satisfied with the air quality, however case 2 supplies with natural ventilation in the morning. The occupants in case 8 express more dissatisfaction. The situation is complex because a number of things are on stake. In the following some of the most central aspect will be outlined. Overall it is about the lack of knowledge, trust and communication.

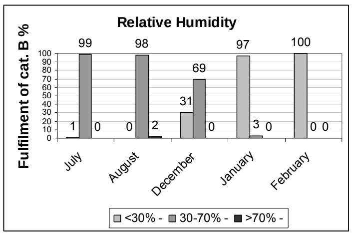
Table 4: The atmospheric indoor environment, CO2 and RF in the summer and winter period in the living room.

<table>
<tr><th></th><th>Case 2</th><th>Case 7</th><th>Case 8</th></tr>
<tr><td>Measurements</td>
<td>



Comments: In January the ventilations system is changed to run at level 3 instead of level 2.</td>
<td>


</td>
<td>



Comments: In January the ventilations system is changed to run at level 2 instead of level 3.</td></tr>
<tr><td>Interviews</td>
<td>The occupants think the air can be dry in the winter, so they often sleep with open windows at night (increased air exchange will just lower the humidity even more). Otherwise they are satisfied with air quality. Even so they supply with natural ventilation in the morning like they are used to, because they think there is a need for it (It can not be stated by the interview if they continued doing so after the air exchange was increased).</td>
<td>The occupants think the air is fresh and healthy and not at all humid or heavy. They think it's great to live with a mechanical ventilation system, because they do not need to open the windows as they did before. Previously, they could smell that they had to open the windows in the morning. Today they sometimes use the ventilation system actively, e.g. when the wife cooks and they have people over they turn it up. They think it is very easy because they just have to press one button and the air change becomes higher in one hour. After one hour, they can press the button again.</td>
<td>If there is only one person at home the occupants do not think the air in the house is heavy, but with five og six adults, the air becomes heavy in a few hours. They want a high air exchange rate in the house – so they cannot see or smell that they are smoking in the house (to achieve that, the air exchange rate have to be about ten times higher). They feel the ventilation system is not running correctly. The occupants think, they have been more ill in the new house – it is very dusty and their noses are blocked. They supplement by natural ventilation both summer and winter.</td></tr>
</table>

Firstly the service man of the ventilations system gives the occupants wrong information and it is exemplified in the following interview dialog:

… Interviewer: *"Does this mean that you ventilate extra by natural ventilation?"* Occupant: *"We have to do so – three to four minutes each hour and that is when the ventilations system runs on step 4. It is because it is so hot in here."* Interviewer: *"Do you also ventilate extra by natural ventilation in winter?"* Occupant: *"Yes, yes, because we only had the ventilation system running on step 2, as they (the* *service man) said we should. It should not run on a higher level than step 2, because otherwise the heat can not keep up."* Interviewer: *"Why do you have a need to open the windows in winter?"* Occupant: *"There air quality is poor in here ... we needed some fresh air. But it should not be necessary when you have a ventilation system."* (Case 8).

The service man is not well informed about the ventilation and heating system, because the system should be able to produce heat no matter what step the ventilation system runs at, as long as it is designed correct. The occupants think the performance on step 2 results in poor indoor air quality and therefore they react by using natural ventilation to improve the conditions. Additionally, this results in lager heat losses than if running the ventilations system at step 4, because the fresh air bypasses the heat recovery in the ventilation unit. Then the ventilation system needs to produce even more heat. This shows lack of knowledge on two levels. The service man misinforms the occupants, because he lacks knowledge about the system. And the occupants are not familiar with the principals of the heat recovery in the ventilation system. He is familiar with natural ventilation as the source to fresh air. The occupants lack knowledge about the consequences of different behaviours in passive houses.

Another aspect on stake is the mistrust to the mechanical ventilation system which the last statement in the above dialog and the dialog below shows. The systems in most passive houses are characterised by inlets in the least polluted spaces like living room and bedrooms, and outlets in the most polluted spaces like bathrooms and kitchens.

Occupant: *"... It does not make sense. It should not be that way; each room must have an inlet and outlet ..."* Interviewer: *"You would like an inlet and outlet in each room?"* Occupant: *"Yes, then you get ventilation in all rooms. Up in the bedroom, where we close the door, we have an inlet and such a small slit under the door. It creates draught on the outside of the door…On first floor we do not have an exhaust, because our bathroom door is closed. It's normal to close the door into a bathroom. The exhaust in the bathroom should ONLY work for the polluted room, not for the adjacent spaces ...* (Case 8).

The mistrust can psychologically affect the general experience of indoor environment and maybe enhance or distort the perception of the situation. E.g. the occupants express that they have been more ill since they moved in. This study does not doubt the fact that they have been ill, but maybe the general perception of the situation is intensified – the experience of being ill is made worse.

Regarding the humidity all measurement shows that it has been dry in the winter period. It was expected that the air will dry out, because the outside temperature during the winter has been very low and contribute to dry air inside. Case 2 is the only case that actually has experience the air being too dry; they "solve" the problem by opening the windows at night – a solution that just increase the problem. Again, as seen above, the occupants do not have sufficient knowledge about the indoor environment – the thermal dynamics - and act contrary to the principals. The occupants in case 8 did not directly express the experience of the humidity but was more focused on the general air quality and how the actual system functions, as seen above.

It can be contradicting to solve both the problem with too high CO_2 levels and the low humidity. The CO_2-level can be reduced by increasing the air change. An excellent solution – simple understandable and easily to use for the occupants, could be the solution seen in case 7. It only takes one touch on one button to increase the air exchange for one hour. Another possibility is to make the ventilation system more automatically and let the air change depend on the CO_2 level (the temperature and the humidity). It can be difficult to solve the problem with the low humidity by lowering the ventilation rates, because it will increase the CO_2-level. Adding moisture to the ventilation air can create other problems with e.g. mould in the system. Additionally, the building industry has a great resistance to such solution. What is important to be aware of is that this problem will also occur in "normal" houses, with the same air change.

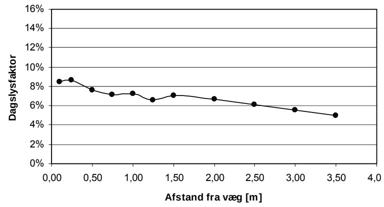
Daylight Conditions

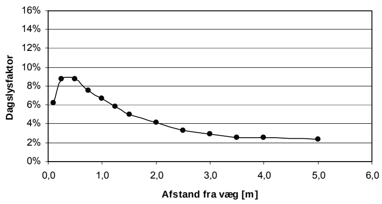
The daylight conditions have been measured in two different places in the common rooms of the three cases. The graphs in table 5 show that all cases fulfil the requirement of minimum 2% daylight factor, even in the back of the room. It means that the overhang of the houses does not have a negative influence on the daylight conditions, and the depths of the living rooms are suitable. The experience from the occupants fits very well with the measurements. In case 7 in the dining room an opposite

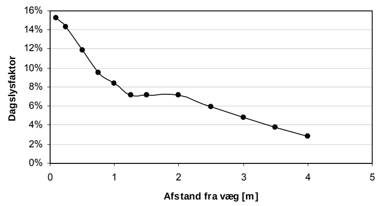
window in the kitchen improves the daylight factor considerable. Additionally the living room is relatively narrow. The occupants express it like this:
"It is very nice when the sun comes up ... and it goes down that way. It is really nice. We have enough daylight, more than enough. When we want to watch a movie in the daytime, some times it is too much when the sun is shining, then we use the blinds" (Occupant, Case 7).
The occupants actually think they have too much daylight some times. On a sunny day the daylight factors will be even higher than the measured, because it by definition is measured on a day with overcast sky.

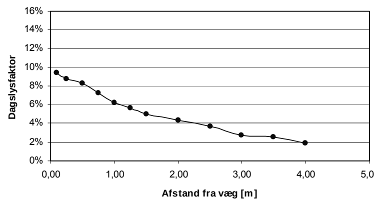
Also the eastern orientated window in the living room in case 8, which is smaller than the windows in the dining room, delivers satisfactory level of daylight, even with a room depth of 4m. The occupants state it like this:
" In here (the dining room), the daylight is fine ... You can read the newspaper; you can do all those things without turning on extra lights. That is fine. We can do the same in the living room." (Occupant, Case 8).
Maybe it is not so surprising that the daylight conditions are fulfilled very well, because the focus on daylight has always been an important part of the architecture. Especially Danish and Nordic architects have an even greater focus on daylight, because the light is less intense and therefore more "valuable" [18].

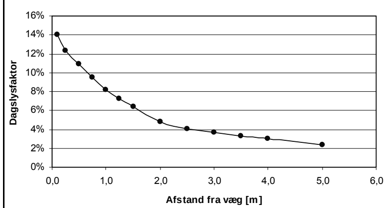
Table 5. The table lists the daylight factors of two different positions in the common rooms and the description of the occupants' experience of the daylight.

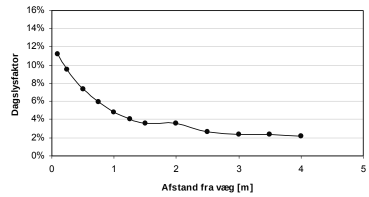
<table>
<tr><th></th><th>Case 2</th><th>Case 7</th><th>Case 8</th></tr>
<tr><td>Measurements</td><td>

Daylight factors of case 2 in the dining room (south-north direction).</td><td>

Daylight factors of case 7 in the living room (south-north direction).</td><td>

Daylight factors of case 8 in the dining room (south-north direction).</td></tr>
<tr><td></td><td>

Daylight factors of case 2 in the living room (south-north direction).</td><td>

Daylight factors of case 7 in the dining room (south-north direction).</td><td>

Daylight factors of case 8 in the living room (east-west direction).</td></tr>
<tr><td>Interviews</td><td>The occupants respond positive to the daylight conditions, even though the black coloured blinds sometimes takes up the daylight.</td><td>The occupants are satisfied with the daylight conditions.</td><td>They are satisfied with the daylight conditions and also state satisfaction with the living room situated in the north-east corner of the building.</td></tr>
</table>

Acoustics

The noise and experience of sounds is the last topic of the indoor environment to be presented. The measurements show that none of the cases live up to class B regarding the reverberation timer without furniture, see table 6. How the result would have turned out with furniture is hard to tell. It depends both on the kind and the amount of furniture in the room, which can differ in each case. Instead the measurements are more comparable without furniture. In case 7 and 8 it is doubted that the reverberation time would be lowered to 0,6 seconds solely by adding furniture in the room. Case 2 on the other hand might fulfil the requirement with furniture.

Table 6: The table lists data from both the interviews, the measurements of the noise from the ventilation system, the reverberation time in the living room and the theoretical calculated reverberation time, based on Sabine's formula [19]. Furthermore, the acoustical initiatives of the three cases are presented by pictures.

	Case 2	**Case 7**	**Case 8**
Acoustical initiatives in the living spaces	 Acoustic plaster	 Lists	 Squares with perforate acoustical plates
Average <u>measured</u> reverberation time (125-4000Hz) Without furniture.	0,79	1,23	1,40
Average <u>calculated</u> reverberation time (125-4000Hz) Without furniture.	0,59	1,77	1,38
Noise from the ventilation system (Measured on standard operation, step 2).	≤ 25dB	≤ 25dB	≤ 25dB
Interviews	The occupants experience a good acoustic condition in the house, but they experience noise from the ventilation system when it runs at step 3, therefore they turn it down to step 2.	The occupants think the acoustical experience in the house is perfect, with no echoing or dead sounds. They do not experience noise from the ventilation system.	The occupants experience a very bad acoustic in the house and it disturbs their everyday life in the house. They experience noise from the ventilation system if it runs on the highest step (4), which they prefer, but when music and TV is running they cannot hear it.

The pictures in table 6 show three different initiatives to improve the acoustical conditions in the rooms. Two of them are actual acoustic solutions, where the roof in case 7 is a “normal” ceiling. In other studies about the design process behind the Comfort Houses, it became clear that the designers in case 7 originally wanted to have regular acoustical ceiling, but it was changed because of financial prioritisation [6, page 39]. Even though the design team behind the house in case 8 has taken acoustical initiatives with installing perforated acoustical plates in parts of the ceiling, the measurements of the reverberation time is very high, due to the high rooms and heavy materials. The study about the design processes show that the majority of the consortiums based the acoustical decisions on experiences of previous building projects [6, 16]. Few consortiums have had dialog with an acoustic expert. As seen in the table simple calculations of the reverberation time based on Sabine´s formula [19] gives a very good indication of the reverberation time compared to the measured. If calculations like this have been conducted in the design processes others and better solutions might have been selected. On the other hand, if the demands in the tender document have been defined clearer, the focus has possibly been larger.

Comparison between the measured results and the interviews shows that there are good correlations. Case 2 and 7 has the lowest reverberation time and none of the occupants complain about the sound in the rooms.

Interviewer: *"How about the noise in the house? Is it ok or could you use some more absorption of the sound?"* Occupant:*"No, I think the sound is ok."* Interviewer: *"It is not too dead or - ?"* Occupant: *"No, it is just perfect."* (Case 7).

In case 8 the highest reverberation time is measured and the occupants are also the most dissatisfied, illustrated in following quote:

"This is the noisiest (house) I have ever lived in. The room up there, if I fart, you can hear it all the way down to the living room. It's so crazy. It is the same the other way around. ... It is totally poor, very poor. All the plates there (perforated acoustical plates) ... they do not work ... they have never worked ... the sound here – yeah you can indeed hear it now. Even though we have pictures and flowers, which should break the acoustic – it does not break… It's actually quit annoying. You can not sit anywhere and talk without disturbing the rest of the house." (Occupant, Case 8.)

The measurements of the noise from the ventilations system show that all cases fulfil the demand of 25 dB or lower in standard operation – step 2 (the exact value is not listed because the meter can not measure lower than 25dB). Even though cat. B is fulfilled the occupants in case 2 experience noise from the ventilation when it runs on step 3. The occupants therefore turn it down to step 2. The occupants in case 8 run the ventilation system on step 4 in the summer. They feel disturbed when music or TV is turned off.

Discussion

Overall, the study shows that the occupants' experiences are consistent with the measurements of the indoor environment and that about half of the topics investigated fulfil the demands, see table 7. The concept of passive houses is new to the building industry in Denmark and the pilot project of the Comfort Houses is one of the first proposals. That these cases did not fulfil the comfort level better does not mean that it is a bad idea to construct passive or low energy houses. Instead we have learned from these pilot projects and can improve the next generation of passive houses. The measurement project continues to run until 2012 and includes five more Comfort Houses than included in this paper; it will generate even more knowledge about this field.

Barriers of fulfilling category B lays in the conflict of some of the investigated topics e.g. the CO_2 level and the humidity can be difficult to fulfil at the same time as seen in the winter period in this study. Additionally, some of the approaches regarding energy savings conflict with the indoor environment e.g. the big windows to the south, which deliver passive solar heat gains in winter, can be a problem in the summer and result in excess temperatures if no precaution are taken.

Table 7. The table sums up the results both from the measurements and the interviews. (-) means category B is not fulfilled or the occupants are not satisfied, (+) means fulfilled or satisfied and (0) means the data cannot confirm clearly either way. (+/-) means both is present in the period.

	Case 2		**Case 7**		**Case 8**	
	Measured	Interview	Measured	Interview	Measured	Interview
Thermal indoor environment, summer	-	-	-	-	-	-
Thermal indoor environment, winter	+/-	+/-	-	+/-	+	+/-
CO2 level, summer	+	0	+	+	+	0
CO2 level, winter	-	-	+	+	-	+/-
Humidity, summer	+	+	+	+	+	0
Humidity, winter	-	-	-	+	-	0
Daylight	+	+	+	+	+	+
Reverberation time	-	+	-	+	-	-
Noise from ventilation on normal operation	+	+	+	+	+	+
Noise from ventilation on high air change	0	-	0	+	0	-

The fact that the CR 1752 [11] (developed to offices buildings) is used to evaluate indoor environment in housing means that we have to be careful with what we conclude. The comfort level of the occupants in dwellings is often much more individual e.g. some wants 20°C in the living room where others prefer 23°C or some wants a cold bedroom where others wants a warm.

During the comparative study between the three cases and the measured results and the interviews different problems have evolved mainly because the interviews have been highly helpful to explain some of the measured conditions. It is mentionable that the occupants' experience might have been influenced by the measuring equipment, which is located on the walls in a height of 160cm from the floor and therefore are very visible. The equipment has a display showing the actual measured data, therefore one could imagine that if the occupant e.g. reads 19.5°C on the measuring device, the occupant becomes aware that the temperature is below 20 ° C and may therefore feel that he/she freezes, although it is not the case. Despite this, the occupants' opinions are still important to get a more detailed picture of the indoor environment, since measurements usually only explain *how* the situation is, the interviews can explain *why* it is as it is.

Initially, we have seen design related problems which are dependent on the design decision made by the design team, which in these cases are cross-disciplinary design teams. Two reasons can be identified to have an influence on the design decisions. Firstly, the demands to the comfort in the Comfort Houses have not been fully clear in the tender document and therefore the design teams have individual approaches, which in most cases result in making decisions based on previous estimated solutions as other studies of the Comfort Houses show [16]. It is not regular practise in the building industry to document single-family houses in such details as discussed in this study. But if we want our future home to be comfortable and wants to call them Comfort Houses the building industry need to change practise and in a greater extend document the indoor environmental aspect e.g. by hour by hour dynamic simulations of the thermal indoor environment or calculate the reverberation time instead of selecting standard solutions based on previous experiences. Passive houses or Comfort Houses are not standard solutions – yet.

Secondly, the occupants have not been well informed about the conditions and assumptions for the system.

“The design assumptions shall be listed in the operational guide for the ventilation or air-conditioning system and it shall be stated that the indoor environment for which the system is designed can only be achieved if these conditions are met. Owners and users of the buildings shall be warned that changes in the application of spaces, or in thermal load or pollution load, can result in the system being unable to meet the indoor environmental requirements for which it was designed.” [11, page 8]

This is what the CEN1752 states are necessary if the indoor environment in offices should be fulfilled. This has not been done in these cases. If the occupants had been well informed about the conditions and assumptions for the system they might have had different behaviours and maybe had more realistic expectations to the system and indoor environment of the house. Instead we have seen that the occupants behaviours and understandings of the indoor environment have a highly affect on the indoor environment. In some cases they do what they find logically to do or do what they have been used to do in their previous home. And we have seen that other aspects come in as a higher priority than the indoor environment e.g. the safety and security of the house and the occupants. Physiological and social aspect can therefore be more important than the indoor environmental aspect. Again, this could be expected because the occupants are not well informed about how to live in a passive house and how to adjust the indoor environment.

“The relationship between indoor environment factors and complex human behaviour is thus not simple. Still, the indoor environment must meet the diverse needs of the occupants whose interests frequently conflict.” [20, page 488]

Philomena M. Blussen states that we need to take a more interactive top-down approach, because different internal and external drivers can influence the wishes and demands of the occupants which also change over time [20]. Meaning that a solution could be to involve the occupants to a greater extend in the design process. But Philomena M. Bluyssen also states that it is not simple, because occupants process information both consciously and unconsciously:

“It is difficult to pinpoint one single method as the best. …it is important to realize that the way we evaluate our environment (perception) and the way we respond to our environment (behaviour) are two different processes, and, we process information consciously (cognitive) and unconsciously (emotions).” [20, page 491]

Some might argue that some of the indoor environmental strategies like natural ventilation, solar shading and air change rates need to be automated. But is that the way forward? Svenja D. Jaffari and Ben Matthews believe that the occupants instead need to become aware of their practises instead of becoming passive objects [10]:

“We suspect that taking autonomy away from people is more likely to result in diminished (not improved) understandings of the correlation of their actions with sustainable living; that the reason for the system’s particular actions at particular points are not likely to be transparent to those who must live with their consequences; and that the loss of human autonomy and control is as likely to generate creative ways of ´working around` the system rather than straightforward, energy-efficient compliance with it. In contrast, we regard it as essential to engage people in the change toward energy efficient comfort practice, making them aware of their current practice and challenging some of their existing habits with the aid of technology design.”[10, page 9]

They suggest more innovative solutions that confront the occupants with their behaviour and effect on the indoor environment instead of equipping the house with automatics. The interest in focusing more on the occupant and their behaviour and understanding of the energy and indoor environmental practices is further confirmed by Raymond J. Cole et al [21]. Here they think we need a broader view on comfort, because the concepts of buildings are evolving. They think occupants or inhabitants should become a more active and engaged part of the designing, maintaining and performance of the comfort – the indoor environment - instead of automating the building. The notion of comfort needs to be “re-contextualised”. The standards largely ignore the behavioural aspects of comfort. Instead they believe in *interactive adaptivity* – a new conceptualisation of comfort, where communication and dialog occurred at all stages of design and occupancy:

“A dynamic and complex building system with a participatory process, interactivity between inhabitants, and between inhabitants and building elements can adopt to changing conditions (…), resulting in a fluid but robust design that is responsive to social, ecological, end economical conditions over time…The goal is to create a building in which the building inhabitants interact actively with the

building controls, sensing and monitoring systems in order to produce an adaptive controls and building management environment." [21, page 333]

The above references do not believe in automatic buildings, but believe in education of the occupants, understanding of the occupants' needs and behaviour, which corresponds well with the findings in this study. The occupants are frustrated about not having the ability to control e.g. the temperature or that they have to accept indoor environmental conditions that are unacceptable because of other more psychological and social priorities. It is believed that if the occupants have been a part of the design process or have been informed about the systems and how to act in the house to achieve comfortable conditions the result would have been improved. Additionally, the design proposals could have been tested to a higher degree to make sure that the house in practice would fulfil the comfort levels. The future houses should have a certain level of robustness; therefore it could be highly interesting to integrate more sensitivity analysis in the design process. Instead of using "standard behaviour", what ever that is, in both the energy and indoor environmental calculations, different behaviours could be simulated to test the "limits" of the building and maybe communicate those findings to the occupants to make them aware of what consequences different behaviours can have on the final operation of the house.

Conclusion

The indoor environmental quality found in these cases has showed that the qualitative and quantitative data correspond fairly well with each other. Even though the discussions have had a great focus on what has not worked in the Comfort Houses. Table 7 shows that over half of the areas presented fulfil the comfort level defined in the introduction.

The areas were the indoor environment is not fulfilled is the most interesting because it is from them we can learn. Learn how to design the next generation of Comfort Houses even better. The experience from this study states four different areas which need more focus in future design and construction of passive houses/Comfort Houses in Denmark:

- Firstly it is important to define from the beginning the goals and demands of the project, to both energy performance and indoor climate, so the design team know what to aim for.
- Secondly the design process needs to contain sufficient analysis that can predict the indoor environment of the house, which could be other and new analysis than housing designers are used to.
- Thirdly it is necessary to have a greater focus on the occupants' life and behaviour when designing, dimensioning, planning and designing the control of the systems. The user-friendliness is one way for the occupants to handle the systems correct.
- Finally, it is important to inform, educate and communicate to the occupant how to live in a passive house (or any other low energy house). Knowledge and communication is a source to gain trust in the concept for the occupants.

The building concepts need to be more robust so the houses better can handle "ignorant" and difficult occupants and maybe handle if any of the assumptions change e.g. less internal gains which could result in lower temperatures than planned.

This study shows the experiences with the indoor environment in some of the first passive houses in Denmark. Hopefully next generation will learn from this, because the future houses have to save energy and in the process of doing so, it must not be on the expense of the indoor environment.

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Publication 4

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Kvantitativ og kvalitativ evaluering af indeklimaet i Komfort Husene

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RESUMÉ

Paperet præsenterer resultater fra både kvalitative og kvantitative undersøgelser af indeklimaet i projektet Komfort Husene. Husene er nogle af de først certificerede passivhuse i Danmark. Den kvantitative evaluering udføres på baggrund af målinger af husenes indeklima, hvor den kvalitative evaluering udføres på baggrund af semi-strukturerede forskningsinterview med beboerne i husene. Resultaterne sammenlignes for at undersøge, om der er uoverensstemmelser mellem de to metoder, men også for at give et mere udførligt billede af indeklimaet, hvor de kvalitative interview kan bruges som årsagsforklaring af målingerne. Resultaterne viser, at både det termiske og atmosfæriske indeklima kan og skal forbedres for at beboerne oplever komfort. For at opnå dette, er det vigtigt at have indeklimaet for øje gennem hele projektet, både i skitserings-, projekterings- og udførelsesfasen. Derudover er information og oplæring af beboerne efterfølgende også vigtig.

NØGLEORD

Komfort, indeklima, enfamiliehuse, målinger, interview

Figur 1. Oversigt over de otte passivhus-certificerede Komfort Hus. Tre af disse er en del af denne undersøgelse.

INDLEDNING

Komfort Husene er nogle af de første certificerede passivhuse i Danmark (www.komforthusene.dk). Projektet består af otte forskellige enfamiliehuse, som er designet af syv forskellige konsortier. De er derfor forskellige både i form, størrelse, materialevalg osv. Formålet med dette studie er at dokumentere indeklimaet både gennem kvantitative målinger i husene, men også gennem kvalitative interviews med beboerne om deres oplevelser af indeklimaet i huset. De kvantitative målinger er en del af projekter: ”Demonstration af energiforbrug og indeklima i 10 danske passivhuse” (Måleprojekt), hvor der er fokus på både energiforbrug, det termiske og atmosfæriske indeklima, dagslysforhold og det akustiske indeklima. Resultaterne i dette paper vil være baseret på tre af de otte huse, da de resterede ikke var beboet på undersøgelsestidspunktet.

METODER

Til dette studie er der anvendt både kvantitative og kvalitative metoder, som kort gennemgås i det følgende.

Kvantitative målinger af indeklimaet

Der skelnes mellem løbende målinger, som er de målinger der foretages i hele måleperioden, og spotmålinger, der foretages under enkelte besøg i huset. De løbende målinger er: Temperatur, CO_2, og relativ fugtighed (RF) – alle i værelse, stue, køkken/alrum, soveværelse og badeværelse. Spotmålingerne er: Dagslysfaktorer i stuen. Efterklangstid og støj fra anlæg i stue-køkken/alrum. I dette paper vil der kun være fokus på de løbende målinger i udvalgte rum. Enkelte spotmålinger er præsenteret på Komfort Hus Konference 1 (Komfort Hus Konference 1, 2010).

Tabel 1. Krav til temperatur og middellufthastigheder for hhv kategori A, B og C (CR 1752, 2001)

Aktivitetsniveau	[met]		1,2		
Kategori			A	B	C
Operativ temperatur	[°C]	Sommer	24,5 ± 1,0	24,5 ± 1,5	24,5 ± 2,5
		Vinter	22,0 ± 1,0	22,0 ± 2,0	22,0 ± 3,0
Maksimal middellufthastighed	[m/s]	Sommer	0,18	0,22	0,25
		Vinter	0,15	0,18	0,21

Det termiske og atmosfæriske indeklima vurderes ved brug af retningslinjerne opstillet i *CR 1752* (CR 1752, 2001). I Komfort Husenes udbudsmateriale var der ikke stillet konkrete krav om opfyldelse af et specifikt niveau, men da husene markedsføres som komfort huse, vurderes det, at husene bør opfylde kategori B som minimum. I tabel 1 illustreres kravet til det termiske indeklima i forskellige kategorier, hvor kravet som sagt er kategori B. Husets CO_2 niveau må ikke overstige 660 ppm over det udendørs niveau (370 ppm), dvs. i alt 1030 ppm, for at opfylde kategori B (CR 1752, 2001). I forhold til den relative luftfugtighed (RF) anbefales det i CR1752, at den holdes mellem 30% og 70%. Den nedre grænse på de 30% bør overholdes, da der ellers vil opstår gener i form af tør luft, statisk elektricitet og udtørrede slimhinder. Den øvre grænse på 70% bør overholdes for at undgå problemer med fugt og skimmel i boligen.

Kvalitative interview om det oplevede indeklima

De kvalitative interviews er gennemført, som semi-strukturerede interviews, hvilket betyder at intervieweren har en overordnet spørgeguide, hvor han/hun er i stand til at ændre rækkefølgen på spørgsmålene, eller stille yderligere spørgsmål til hvad der kan have betydning for undersøgelsen (Kvale, 2007). Det kvalitative forskningsinterview, er velegnet, når målet er at forstå en anden persons eller en gruppe af personens oplevelser af deres egen livsverden. Det kvalitative interview varierer fra det kvantitative interview, som f.eks. spørgeskemaer, ved at være mere fleksibelt, fordi intervieweren har mulighed for at stille nye spørgsmål, der følger op på svarene. I en samtale opstår ofte nye indsigter, som kan have relevans for forskningen, som netop det kvalitative forskningsinterview muliggør (Bryman, 2008). Resultaterne fra de kvalitative interviews vil være kondenserede gengivelser fra interviewene.

RESULTATER

Resultaterne vil præsenteres i et komparativt studie mellem de kvantitative og kvalitative resultater i et parallelt forløb under hvert indeklimaområde for hhv. case 2, case 7 og case 8. Dette studie er en del af et større projekt, som indeholder flere undersøgelses felter og for at bevare en sammenhæng mellem disse studier og dette paper er case numrene bevaret, så der er mulighed for at læse andre undersøgelser og sætte disse i relation.

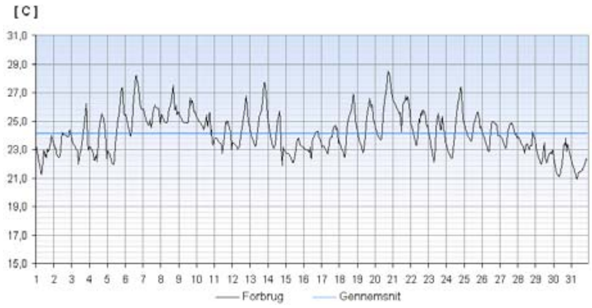
Det termiske indeklima

I de følgende tabeller opstilles de kvalitative og kvantitative resultater nedenfor hinanden.

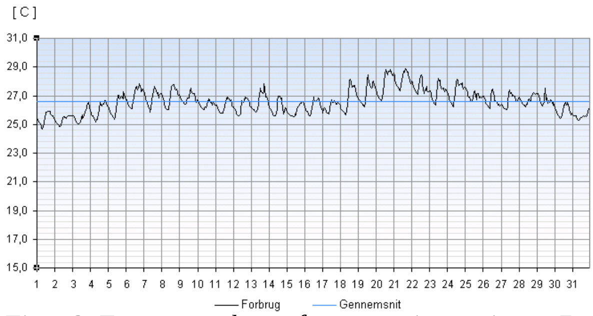
Tabel 2: Det termiske indeklima i sommerperioden.

	Case 2	Case 7	Case 8
Målinger	Tendens til overtemp. i juli og august. Kat. B opnås i ca. 65% af tiden i opholdsrummene.	Meget høje temperaturer (temp.). Gennemsnittemp. ligger i perioder på ca. 26°C. Kategori (kat.) B (minimum A+B) opnås i ca. 30% af tiden i stuen. I værelset mod syd (kontor) opnås kat. B i ca. 45% af tiden, hvor soveværelse mod nordvest opnår kat. B i ca. 70% af tiden.	Tendens til overtemp. i juli og august. Kat. B opnås i ca. 70% af tiden i opholdsrummene.
Interviews	De oplever, at der er for varmt i huset. De har sat indvendig solafskærmning op og prøver at løse det med naturlig vent. og ved at gå rundt i meget let påklædning.	De synes der er meget varmt. De forsøger at løse problemet med naturlig ventilation (vent.), men det hjælper kun lidt, så de har tænkt på at installere en aircondition. De oplever at varmen flytter sig med solen, hvilket betyder, at der er meget varmt i soveværelset og børneværelset når de skal sove. De tør af sikkerhedsmæssige årsager ikke at lade vinduerne være åbne i datterens værelse, når hun skal sove.	De oplever, at der er for varmt i huset. De har sat gardiner op, men synes ikke det hjælper. De synes ikke den naturlige vent. virker godt nok. Vinduerne har problemer med at forblive åbne, pga. låsemekanisme. Derudover kan vinduerne ikke stå åbne i det antal timer som projekteret pga. tyverisikring. Når ingenting hjalp, gik de ud i garagen.

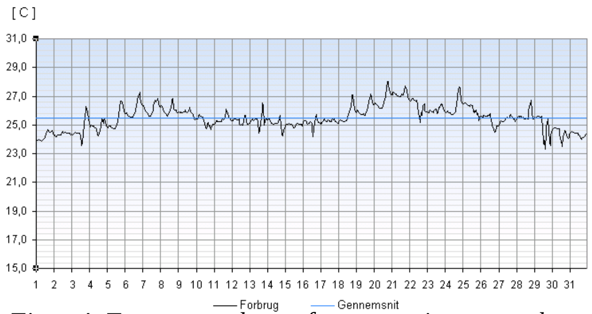
Målingerne i alle tre cases viser at der er en tendens til overtemperaturer om sommeren, hvor case 7 dog i upræget grad ikke opfylder komfort kravene opstillet i undersøgelsen, ses også ved sammenligning af figur 2 og 3. Beboernes udtalelser bekræfter også at der er for varmt.



Figur 2. Temperatur kurv for august i stuen i case 2.



Figur 3. Temperatur kurve for august i stuen i case 7.



Figur 4. Temperatur kurve for august i soveværelse i case 7.

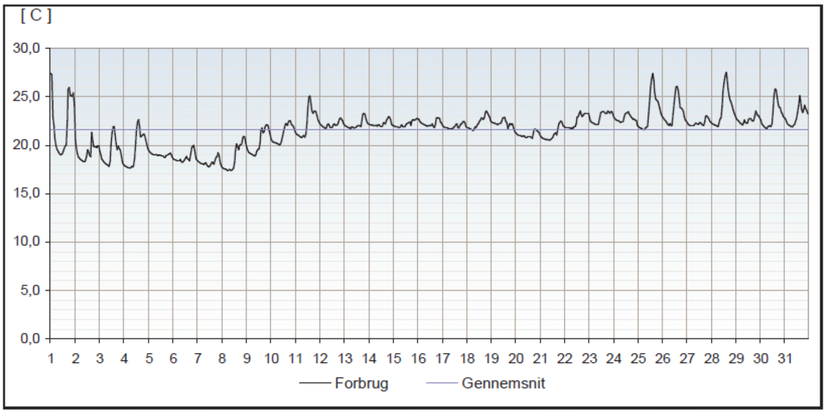
At der i case 7 er væsentlig bedre komfort i soveværelset (vestvendt) end resten af huset, kan hænge sammen med at der udsuges fra badeværelset, som grænser op til soveværelset og at orienteringen er mod nordvest og får først sol om eftermiddagen og aftenen, så perioden med høje temperaturer er kortere, hvilket også ses ved sammenligning af figur 3 og 4.

Derudover kan naturlig ventilation i løbet af dagen også have indflydelse på temperaturen. Sammenlignes det med beboernes beskrivelse af deres adfærd (de åbner sjældent vinduerne i børneværelset pga. barnets sikkerhed når hun skal sove), fortæller dette netop, at de nok anvender naturlig ventilation i soveværelset, som også bidrager til det forbedrede indeklima.

Tabel 3: Det termiske indeklima i vinterperioden.

	Case 2	Case 7	Case 8
Målinger	Temp. falder i takt med udetemp. Kat. B opnås i 62% af tiden i december – værelset kun 13% ad tiden! Problem blev afhjulpet i januar 2010 med el-radiator i stuen på 500W (midlertidigt), derefter opnås kat. B i 97% af tiden.	Kan holde en temp. på 20°C i stuen, men et par grader lavere i værelserne. Januar og februar er der i morgentimerne lige under 20°C. I januar opnås 63 % af tiden kat. B og i februar opnås dette i 74% af tiden.	Temp. Ligger i den kolde ende. Faldende udetemp. ses direkte på indetemp. Laveste temp. 19°C. Kat. B opnået i 70-80% af tiden. Efter teknikkertilsyn ligger temp. i kat. B over 90 % af tiden.
Interviews	De har svært ved at holde varmen når solen ikke skinner. Temp. er ofte nede på 17°C, så de har gået med ski-undertøj og hjemmesko. Efter installation af radiator oplever de ingen problemer med at holde varmen.	De synes der kan være lidt koldt, de kan ikke få mere end 20°C i huset, når der er overskyet. Det er for koldt at gå rundt i T-shirt som de plejer (heller ikke standard påklædning om vinteren). De synes det er dejligt når solen skinner, så stiger temp. 2-3°C. De oplever datterens værelse som koldere end soveværelset. De vil gerne kunne regulere temperaturen.	I starten havde de 19-21°C, som de synes var for koldt, men efter at de har haft service på anlægget er de kommet op på 23°C. Beboerne savner en bedre styring af det termiske indeklima. De oplever at der lidt fodkoldt især på klinkerne i entréen.

I vinterperioden ses det at alle tre cases synes det er for koldt i huset, som målingerne også viser. I case 2 og 8 har tekniske justeringer medført et væsentligt bedre termisk indeklima både målt og oplevet. Årsagerne til behovet for justeringer er af forskellige karakter. Det er både projekteringsmæssige forkerte valg og installationstekniske fejl i udførelsen, som har resulteret i utilfredsstillende indeklima.



Figur 5. Det ses på temperatur kurven at rumtemperaturen i case 2 ligger omkring 22°C efter den ekstra varmekilde blev tilsluttet d. 8. januar.

Det atmosfæriske indeklima – CO_2 niveau og relativ fugtighed (RF)

I tabel 4 ses det at der ingen problemer er med CO_2-niveauet i sommer perioden, hvorimod CO_2-niveauet om vinteren i case 2 og 8 stiger, så de kun opfylder kat. B i 60-70% af tiden. Beboernes oplevelse af CO_2 niveauet kommer til udtryk ved *oplevelsen af tung luft* og det giver case 8 kun udtryk for at opleve, når de har været 5-6 personer i huset i en periode. Derudover udtrykker case 8 en generel utilfredshed og utilpashed omkring effektiviteten af ventilation. Dog skal det tilføjes, at husets beboere er rygere. Umiddelbart kan man tro der er en sammenhæng i case 1 mellem den brugervenlighed, som beboeren udtrykker der er ved at kunne sætte luftskiftet op ved blot at trykke på én knap, og den lave CO_2-niveau, der er registreret det meste af året, men målinger viser at knappen kun anvendes sjældent. I stedet er der sandsynligvis et lavt CO_2-niveau, fordi der kun er tre beboere, hvoraf den ene er et lille barn.

I forhold til måling af RF ses det, at alle cases har det for tørt i vinterperioden. Det er forventeligt at luften vil blive tør, da udetemperaturen i perioden har været meget lav og derved vil bidrage til tør luft indendørs. Beboerne giver umiddelbart ikke udtryk for at opleve at der er for tørt, men emnet får heller ikke så meget fokus i interviewet.

Tabel 4: Det atmosfæriske indeklima CO2 og RF i sommer og vinterperioden.

	Case 2	Case 7	Case 8
Målinger	Om sommeren ligger CO_2-niveauet hovedsageligt i kat. A og B, hvor der i dec. blev registreret højt CO_2 – niveau, kat. B i ca. 40% af tiden. I jan. ændres anlægget fra at køre på trin 2- 3 og CO_2 niveauet ligger derefter i kat. B i 60% af tiden. Der er ingen problemer med fugt i sommerperioden, men i jan. og feb. ligger RF under 30% i ca. 70% af tiden.	CO_2-koncentrationen ligger fint hele året, dog enkelte højere koncentrationer (max 1400). Der er ingen problemer med RF om sommeren, men er under 30% i jan. og feb. i 80-95% af tiden.	CO_2-niveauet ligger om sommeren i kat. A i 95% af tiden, hvor det om vinteren ligger på niveau B i 60-70% af tiden, dog på 90% af tiden i køkkenet. Ingen problemer med luftfugtigheden om sommeren, hvor den tværtimod ligger under de problematiske 30% i 90% af tiden om vinteren.
Interviews	De synes luften kan være tør om vinteren, så derfor sover de ofte med åbne vinduer om natten (luften bliver blot mere tør ved større luftskifte), ellers er de tilfredse med luftkvaliteten. De lufter dog ud om morgenen, fordi de synes der er behov for det (Det vides dog ikke om de fortsætter efter at luftskiftet blev sat op).	De synes luften er frisk og sund og slet ikke fugtig eller tung. De synes det er dejligt at leve med et mekanisk ventilations anlæg, for så behøver de ikke åbne vinduerne, som de gjorde tidligere, og de føler heller ikke der er tidspunkter, hvor de har haft behov for det. Tidligere kunne de lugte, at de skulle åbne vinduerne om morgenen. De bruger nogle gange ventilationssystemet aktivt, f.eks. når hun laver meget mad og har gæster kan hun finde på at skrue op. Hun synes det er meget nemt, for hun skal bare trykke på en knap og luftskiftet er højere i en time. Efter en time kan hun trykke på knappen igen.	De synes ikke luften i huset er tung, hvis der kun er en person hjemme, men er de 5-6 voksne så er luften tung i løbet af et par timer. De vil gerne have et højt luftskifte, det skal være sådan at de ikke kan se eller lugte at der bliver røget i huset (For at undgå dette skal luftskiftet være ti gange større). De har en følelse af at anlægget ikke kører rigtigt, de nævner at de synes de har været mere syge og at der er meget støvet og næsen stopper til. Deres forklaringsårsager er, at der ikke er en indblæsning og udsugning i hvert rum, så derfor bliver den beskidte luft ikke suget ud (Dette vil dog være imod principperne i traditionel bolig ventilation). De supplerer med, at de tror at luften der bliver suget ud i køkkenet kommer fra utætheder i hoveddøren og ikke luft fra rummene.

DISKUSSION

Både de kvalitative og kvantitative resultater viser, at det ikke er helt problemfrit at bo i et passivhus (Komfort Hus). Det termiske indeklima afhænger i høj grad af de passive og aktive tiltag i husene. F.eks. vides det fra tidligere undersøgelser af designprocessen (Brunsgaard, 2009 og Brunsgaard, C. et al., 2009) at ingen af konsortierne bag husene har lavet en dynamisk simulering for at undersøge risikoen for overtemperaturer i sommerperioden. Hvis disse var udført, var der muligvis taget andre eller flere valg i forhold til afskæmning og/eller køling af huset i skitserings- og projekteringsfasen, og det termiske indeklima om sommeren ville have set anderledes ud. At nogle beboere har haft det for koldt hænger primært sammen med de aktive tiltag – varmeinstallationen (ventilationsanlægget). For at undgå problemer skal der i høj grad være fokus på dette både i projekteringsfasen når systemet dimensioneres og planlægges, men også under selve installationen, hvor den udførende skal være klar over, at det måske skal laves anderledes end tidligere. Derudover er indeklimaet (og energiforbruget) også enormt afhængig af om beboerne har den fornødne viden til at ”opføre sig korrekt” i et passivhus. Flere hverdagspraksisser kan være ”ødelæggende” for idéen med passivhuse. F.eks. udluftning med døre og vinduer om vinteren eller at skrue ned (eller helt slukke) for ventilationsanlægget. I dette projekt har beboerne modtaget meget begrænset information om hvad det vil sige at bo i et passivhus. Hvad er tilladt, og ikke tilladt og hvilke konsekvenser har forskellige handlinger på indeklimaet og energiforbruget?

For at forbedre det atmosfæriske indeklima er justeringerne egentlig ikke så store. CO_2-niveauet kan bringes ned ved blot at lave nogle løsninger der har en brugervenlighed, så alle kan forstå det. Det skal være hurtigt og nemt at betjene, som det ses i case 1, med tryk på én knap når der er gæster og luftskiftet bliver højere i en time. Eller måske burde anlægget regulere helt automatisk. I forhold til den meget lave luftfugtighed om vinteren kan det være svært at gøre nogen vha. sænkning af ventilationsmængderne, så det ikke går udover andre forhold, som f.eks. CO_2-niveauet. I stedet kunne beboerne købe flere planter og/eller tørre vasketøj inden døre, så luften får tilført mere fugt.

Generelt set stemmer beboernes oplevelser fint overens med målingerne af indeklimaet. Det skal dog siges i den sammenhæng, at beboernes oplevelser kan være påvirket af måleudstyret, som er placeret på væggene i højden 160 cm fra gulvet og derfor meget tydelig. Måleren har et display som viser de aktuelle måledata. F.eks. kan man forestille sig, at hvis beboeren aflæser 19,5°C på måleren bliver beboeren opmærksom på at temperaturen er under 20°C og vil måske derfor føle at han/hun fryser, selvom det ikke er tilfældet. Trods dette, er beboernes udtalelser alligevel vigtige for at få et mere udførligt billede af indeklimaet, idet målinger som oftest kun forklare *hvordan* situationen er, hvor interviewene kan forklare *hvorfor* det er, som det er.

KONKLUSIONER

Denne undersøgelse viser at det er enormt vigtigt, at der tages hensyn til komforten hele vejen gennem tilblivelsen af huset, for at opnå komfortable passivhuse. I projekteringen skal der laves de nødvendige beregninger og simuleringer, under udførelsen skal de udførende have den fornødne viden til at kunne udføre tingene korrekt. Sidst, men ikke mindst, er det vigtigt at brugerne får en overordnet forståelse af hvilke konsekvenser forskellige handlinger kan have på indeklimaet og i sidste ende også på energiforbruget.

ANERKENDELSE

Målingerne stammer fra måleprojektet ”Demonstration af energiforbrug og indeklima i 10 danske passivhuse”, som er støttet af Realdania. De kvalitative interviews er en del af ph.d. afhandlingen ”Understanding of Danish Passive Houses based on Pilot Project Comfort Houses”, som er støtte af Saint-Gobain Isover Scandinavia.

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Experiences from the design processes of the first "Comfort Houses" in Denmark

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ABSTRACT:
The "Comfort Houses" is the most ambitious building project in passive houses in Denmark until today. Eight single family houses are built and designed by seven different consortiums. Besides fulfilling the German passive house standard the goal was to build the houses according to Danish tradition of architecture and construction. The objective of this research was to clarify the different design processes according to method, tool and teamwork. The processes are evaluated according to the "Integrated Design Process" and the "Traditional Design Process" and show very different take-offs. Analysing the data we can see that: All consortiums agree that it is necessary to work as a team from the early stages of the design process. There is a tendency in all processes that they are not using the tool that are available to document some of the parameters of indoor environment. According to the architectural qualities some of them are often cut back in the process primarily because of cost savings.

1. INTRODUCTION

The most ambitious building project in passive houses in Denmark until today is the "Comfort Houses" [www.komforthusene.dk]. It is a 1:1 scale experiment to see if it is possible to build passive houses in a Danish context according to Danish regulations and tradition of architecture and construction. But also to see if a Danish family likes to live in these houses and to see which problems and barriers this approach gives in Denmark and on the Danish market. The project was initiated by Saint-Gobain Isover Scandinavia and involved building ten passive houses, single-family houses, in the same neighbourhood constructed by nine different consortiums. The consortiums consist both of architects, engineers, contractors and in some cases also manufactures. The houses are finished and available for sale in autumn 2008.

The passive house standard from the Passive House Institute in Darmstadt in Germany is the most well known passive house standard internationally [www.passive.de]. Thousands of houses have been built in Germany, Austria and Switzerland according to this standard. In Denmark passive houses have only been built in the last 1-2 years, therefore we still need to find our own approach. Besides fulfilling the German passive house standard the "Comfort Houses" should also have a high level of comfort – a parameter that the initiators think appeal more to the Danish population than saving energy. The passive house solutions can not be copied directly from Germany or Austria to Denmark because the requirements from the Danish resident's lifestyle, the traditions in the building industry and the architectural traditions are different. Therefore it is important to find at Danish approach, to get passive houses into the Danish market and thereby minimize the energy consumption in housing.

Figure 1: Overview of the Comfort Houses that fulfils the German passive house standard [1].

It was expressed from the initiators that the consortiums should work integrated with both technical and architectural aspects and work as a team, because many design decisions both affect the energy performance, the indoor environment and the architectural quality of the building. But the initiators did not dictate a methodical approach. In the beginning of the detailing part all consortiums got a fixed budget, which was determined on the basis of the expected market value of the house, and including a small sum to cover the extra cost of constructing a passive house.

The objectives of this research was therefore to clarify the different design processes according to method, tools, teamwork and their approach to achieve architectural quality to be able to use this knowledge in future projects with passive houses or “Comfort Houses” in Denmark. The results will be based on seven of the finished houses.

2. METHOD & THEORY

The empirical research of the design processes are analysed trough qualitative focus group interviews of each consortium [Kvale 2009, Bryman 2004]. The interviews are carried out after the semi structured interview method. Each interview is analysed individually and afterwards analysed in a comparative study.

In a design process, especially of low energy buildings, it can be difficult to overview the consequences are of a certain design decision; therefore theoretically the method of the “Integrated Design Process” (IDP) is recommended and there are different approaches available here. The knowledge from the interviews about the practical experience is compared with different approaches of IDP and the “Traditional Design Process” (TDP) to illustrate which kind of processes the consortiums has had. In the following the TDP and the different approaches of IDP are shortly explained.

2.1 The traditional design process (TDP)

The description of the TDP is of course a generalisation but it often proceeds like this: The architect and the client agree on the design concept consisting of the form concept, orientation, fenestration and the exterior appearance like characteristics and materials. Then the engineers and consultants are asked to implement or design systems for the building. This procedure is quite simple mainly because the actors in the process are limited and they are implemented linearly, see figure 2. The linear process results in difficulties in optimizing or even impossible to optimize the design according to e.g. energy and indoor environment, because the expertise comes in late in the process. This is a problem especially when designing passive houses where even more parameters are in action than in standard buildings fulfilling the conventional level of performance.

Figure 2: The Traditional Design Process – a linear approach.

2.2 The integrated design process (IDP)

In the last several years we have seen a lot of different approaches to IDP being developed. Generally they wish to fulfil the same goal but have different visions of aiming. They all focus on the importance of integration of aspects of both engineering and architecture in a holistic synthesis in order to solve the often very complicated problems connected to the design of a building. Although they have the same goal they still vary in some areas: Main parameters in focus in the method, steps and milestones, implementation of actors and their position etc. It often depends on who has developed the method and the developer's main professional interest. Most approaches to IDP have an iterative process as illustrated in figure 3.

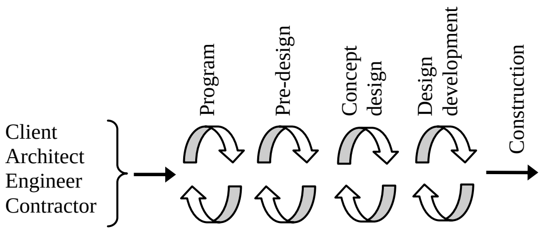

Figure 3: The Integrated Design Process – an iterative linear approach.

Examples of IDP could be:

- International Energy Agency (IEA) Task 23: Optimization of Solar Energy Use in Large Buildings, subtask B (Task 23 IDP) [Löhnert 2003]. In this approach the client takes a more active role than usual, the architect is a team leader instead of a sole form-giver and the different engineers, including an energy specialist, takes an active part in the early stages of the process. The process is based on specialist knowledge of each actor. The design develops through iterative operations.
- The Integrated Design Process, Architecture & Design, Aalborg University (AOD IDP) [Knudstrup 2004, Knudstrup 2006]. This approach is developed as a method for architecture students at Aalborg University, Civil Engineering in Architecture & Design. It means it is developed from an architectural point of view. The work is based on the architects design process applying some technical engineering parameters and tools in the programme. All persons carry a new professional interdisciplinary profile that aims at integrating architectural skills and the necessary engineering skills and tools to fulfil the goals.
- Integrated Design of Low- Energy Buildings, Technical University of Denmark (DTU "IDP") [Petersen 2008]. This approach is one of the newest methods in field and developed from the engineer's point of view. The procedure in this method is to find the optimal technical solutions in an iterative process between the technical aspects using a tool developed for the purpose. In the end the architectural aspect is incorporated. The question is if the process can be called integrated because the iterative process does not involve the architectural parameters.

3. THE TEAMWORK

In the interviews the consortiums agreed that the teamwork in this project was different than they were used to, as it in most cases was based on the TDP. All consortiums talked about the importance of a closer teamwork earlier in the design process and that it is the way forward to be able to make good passive house and low energy building designs in the future. But how they see the teamwork and to what degree the teamwork has been closer, vary from consortium to consortium. The different kinds of teamwork can be classified in three types based on the actors in the TDP.

- Type 1. Incorporated one more actor in the early stages than usual e.g. architect + engineer, but the main influence on the design solution is still from one profession. Later other actors are involved.
- Type 2. Take-off with an interdisciplinary teamwork, but still the design solution in mainly influenced by one or two professions or are based on their premises.
- Type 3. Work as a team together on all aspects of the design e.g. both architect, engineer(s) and contractor from the early stages of the design process.

The different types of teamwork are closely connected to the methodological approach of the design processes described in the previous paragraph. It will be further outlined in the next section.

Besides experiencing the need of teamwork between architects, engineers and contractors, the consortiums within type 3 also wanted to bring in the subcontractors earlier in the process because they are specialist of their own products and their knowledge is also important to integrate to be able to design better solutions both aesthetically, functional, technical and economic.

4. THE APPROACHES TO THE TASK

As mentioned earlier the consortiums were not told to use a certain method in the design process of the houses. The interviews showed that all consortiums have worked without a method. Instead they have worked with different strategies. E.g.:

- “Make it simple” as a main guideline
- Outlining a number of focus parameters – some both covering technical and architectural aspects
- ”Trias Energetica” principle [www.triasenergetica.com]
- Performing analysis of consequences of different design solutions
- Or simply designed solutions on the safe side.

These strategies are more and less integrated according to the different definitions of IDP. To illustrate the different consortiums approaches to the process individually and compared to each other, their approach are placed on an IDP indicator in figure 4. The location is chosen from a) the main actor or cooperation of different actors b) when and how the actors are positioned in the process and c) the type of focus parameters in each case. It says something about the starting point for the project and when the architectural and technical aspects are combined – from the beginning or later in the process, if they are combined at all.

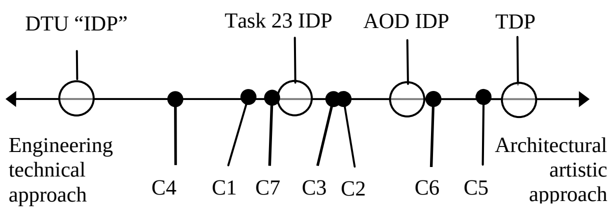

Figure 4: All the consortiums approaches´ (Cn) are placed at the IDP indicator. The scale has in one end the engineering technical approach and in the opposite end the architectural artistic approach. They represent the most extreme ends of how to approach a building design. In between them different approaches to building design is placed - the TDP and different approach to IDP. The placement is based on literature study of the different methodological approaches.

The figure shows that the cases are widely spread on the indicator and that the majority of the consortiums have worked very different from the TDP even though they were not introduced to any IDP method. The reason for that might be that the initiators of the project asked the participants to create a consortium and work in teams and share knowledge, even across consortiums. This teamwork must have made some consortiums approach the process more integrated than usual. Maybe they also felt the need to discuss the different aspects to be able to make the right solutions because the concept is new.

The processes have of course not been without problems including the most integrated processes. Consortium 2 has experienced that the boundaries between the professions is more unclear than in a TDP. Even if all actors are present in the discussion and all agree on a decision, it might not be clear who is doing what and when. In consortium 3 they have experienced that even if they have agreed on a certain design aspect, it later turns out that they had different understanding of the decision based on their different professional traditions. In consortium 1 the team is so focused on the “new” technical engineering aspects that the architect nearly forgets to focus on the architectural qualities of the house. When the architect was asked about which architectural qualities have been important in the design, the answer was that they were closely connected to the energy goals and in answering the architect became aware that they had nothing to do with architectural qualities and says: *"I do not know what architectural qualities there are in that (the answer). I guess it is more some kind of program parameters."(The architect, consortium 1).* The architect was hypnotized by the quantitative goals and the architectural qualities came in as a second priority.

In consortium 4 the project had so binding constrains that the architect was not able to design good architecture within these. It resulted in architecture, but not as good as it could be. *"Of course you would wish that there had been constructed something … a piece of architecture, right? But because it should express something that both is typical to a Danish standard house, at the same time something that the contractor could bring out to the market and at the same time be the cheapest, then it had a lot of constrains in relation to the architecture … The technical part is the most important heaviest in a single-family house in one storey. I think so as an architect. It means that you do not sit down and sketch by a loose hand. You draw a rectangle and send it to the engineer and ask: ´Is it better now? ´ There is no architecture in that, in principal. ´Should it be a little lower? Arh 20 cm lower ceiling inside´ … It has been a challenge according to think architecture and at the same time think of a passive house in one storey … "(The architect, consortium 4).*

Opposite, in consortium 5, the engineer felt too constrained because the architectural aspects were too fixed. *"I think is was a bit annoying that you in principal sketch a house, and there was not a long time available to do that, and win the competition, wupti! Then you have promised how it should look like, what building services it has and … the cost. Then you are extremely constrained, right? And that is before you have had the time to consider the design, because you have not had the time to calculate and you actually do not know very much (about passive houses). … What was it that we were about to do? We had to learn, but we could not use that for anything because we had promised (how it should look like) … we could have changed a little on the windows ... But we had promised how the house should look like and it is really the architectural idea how the window is placed and turns that direction. Then you cannot change that." (The engineer, consortium 5)*

When the consortiums were asked to mention some recommendations to others in the building industry they pointed out:

- It is important to have a good teamwork early in the design process and work interdisciplinary.
- The teams have to see the design task as a joint mission and that all aspects concern everybody and all have to be enthusiastic about the project.
- The energy aspects have to be integrated into the architectural expression from the beginning of the design process to achieve good solutions. It means we have to work integrated.
- Draw up some guidelines that should be followed in the design process e.g. define main focus parameters both covering architectural and technical parameters.

5. THE TOOLS

In an IDP it is essential to use some kind of tools to demonstrate that the requirements are fulfilled but also to ensure that the design is moving in the right direction during the process. The tools can be divided into three categories: Architectural, energy use and indoor environment. There is a tendency in which tools the consortiums have used, see table 1.

Table 1: The tendency in which tool the consortiums use during the design process.

Architectural - AutoCAD - Hand sketches - Some 3D modelling in the sketching phase
Energy consumption - Be06 in the early stages of the sketching phase (Danish software for calculating energy consumption) - PHPP in the detailing part or in the whole process (Passive House Planning Package [www.passive.de])
Indoor environment - Static calculations of the risk of overheating in PHPP. - Other indoor parameters as light and noise are not documented by calculations. The solutions are instead chosen according to the experiences from other building.

In other projects they also use the same architectural tools and Be06. But the main difference in this project was that the houses had to be certified as passive houses and therefore the energy consumption had to be documented by PHPP, which was a new tool for most consortiums. The opinion about the PHPP tool varies, but it has been a challenge for most consortiums to get the needed input data, because the detailing of the design has to be higher than usual e.g. detailed calculation of the specific cold bridges and more detailed data of products. The PHPP tool has been used continuously through the detailing process to make sure that the project is moving in the rights direction and fulfils the demands. What is interesting is the way PHPP has been used? One way of using the programme is to:

- make at design decision and afterwards check if it is alright with the requirements, if not, redo the design and calculate – "Trial and error"

or

- calculate a reference building and try different changes to that, list the changes and the consequences on the energy use and then discuss what direction to go with the design – "Analysis of consequences"

The latter has been a success for the consortium using this approach and especially a success for the architect, because he gets a common understanding of which design decisions has influence on the energy and how much. They also tried to extend the analysis with an economical parameter. Then the contractor also became active. The first approach is instead split up in specialities, one designs and one calculates. Not saying that it can not be successful to use this approach, but the communication becomes an even more important factor in the teamwork.

According to documentation and analysis of the indoor environment, it has been very limited which tools they have used. In almost all cases the thermal environment according to overheating was calculated in PHPP, but the indoor environmental aspects like light and noise have in the majority of the cases only been discussed. The design solutions were then based on well known good solutions or based on solutions that might accommodate a common well known problem. The consortiums know the tools, but they are not used to work with them especially not on single family houses. The problem in not using the tools is that the solutions they pick are based on existing building cases. The existing building stock are constructed totally different than the "Comfort House" and therefore they can not be sure it will react the same way e.g. the walls are much thicker than in a standard house and can result in less daylight coming into the rooms and the orientation of the house is much more fixed. Furthermore many of the existing buildings have poor indoor environments and the right solution to the problem could be several. E.g. many complain about acoustics in existing dwellings. If it is not calculated and existing examples are poor, how do we know, when we reach comfort?

6. THE ARCHITECTURAL QUALITIES

The architectural concept was in all cases defined when handing in the proposal to the competition. Only one consortium changed the whole concept after they qualified for the project but that was a demand from the competition board. In many cases the architectural concept was developed according to passive aspects like compactness, south orientation, passive solar shading etc. Others also worked with a concept of prefabrication or concept of Danish standard housing. It has been investigated if this initial design concept could last through the design process to the final solution or if the consortiums had to make major changes to it to be able to certify the house, to construct it within the financial boundaries and in the same time secure a comfortable indoor environment. No consortiums had to make major changes to the initial design concept, but some things were changes e.g. the amount or size of windows, their choice of materials, shrinking the size of the house and more. It does not seem to be much but some of the actors think it weakened the architecture. Some changes were made to be able to fulfil the energy requirements and the district plan according to building lines, but most changes were made because of the financial constraints. This illustrates that fulfilling the energy requirements is a smaller challenge than fulfilling the financial requirements. It also shows that the indoor environmental parameters have not been a reason for the architectural changes. The fact that the economy plays a big role in the level of architectural qualities is closely connected to the fact that architectural qualities are qualitative parameters which can not be transformed into clear definitions and powerful documentation. Therefore architecture has little power in a discussion with other actors in the project [Jensen 2006, Knudstrup 2007]. It is therefore very important in the beginning of a project to discuss the architectural qualities and maybe use some reference pictures to support a common understanding of this. It is a big job to do that because not even architects necessarily agree on how to understand different qualities. To strengthen the common understanding it is important that all actors care for and are enthusiastic about the project also the contractor. Or else it is hard to open up for new insight which is necessary in order to discuss architectural quality in relation to the other aspects in the project – especially economics. The teamwork between the different professions is also important because it create an ownership to the project and trough that create an interest in finding good architectural solutions as well.

7. CONCLUSION

All consortiums state that the future design approach is something different than TDP. The future design approach take-off differently and create a different cooperation between the actors in the design process. The analysis show that it is not enough for the client to say that the actors have to work closely together from an early stage in the design process, as illustrated by the seven cases which have shown very different ways of “close cooperation” compared to the TDP. It is therefore important in a design process to define both the teamwork and the methodological approach, as these are closely connected. Therefore if you define a certain type of teamwork you also indicate a certain methodological approach, and vice versa. The investigation show that even in the consortiums where they have worked closely together in an integrated process, they still had some problems mainly about communication and understandings of each others professions.

Some consortiums thought it was only a period they needed to work in an integrated way - until the architect got a better and general understanding of the “new” aspect of building design. But should we go back to letting the architect be the sole form-giver? And let the engineers be the problem-solvers? Do we think it will result in better buildings? The risk in IDP is that the architectural qualities are overruled by all the engineering aspects which also were seen in some of the solutions in this project. That is the whole issue of the differences between engineers and architects [Knudstrup 2006, Hansen 2007]. Architects are generalists and know something about a lot of things e.g. aesthetic, experiences of room, light, materials, everyday life, sociology, psychology and much more. They are trained in combining all these aspects while engineers are specialist and know something about a specific area of the engineering field. Therefore the architect in developing the design is up against integrating several technical quantitative aspects raised by the engineering specialists with his/hers unclear and less well defined qualitative parameters. I think to be able to integrate all the “new” energy and comfort requirements and still design aesthetic and functional buildings in the future, we need to further develop the integrated design approach with a method or a tool to secure architectural qualities in building, especially in low energy buildings and passive houses, where a lot of other aspects are in play.

According to the tools used in this project it is problematic that hardly any tools are used to study or document the indoor environment. That is, as mentioned earlier, a problem because the consortiums do not have the experiences with this kind of houses and do not know the right solutions for sure. Why not do it correctly the first time and use the tools available? People have to live in the houses for more than 50 years.

The result of the analysis seems to aim for a methodological approach and type of teamwork in the IDP indicator region of Task 23 IDP and AOD IDP, see figure 4. It is concluded because of the agreement from all consortiums about the close teamwork from the beginning of the design process and on the recommendations from the consortiums listed earlier in this paper. There is also a more satisfied spirit behind the consortiums placed in that IDP indicator region, satisfied with their teamwork, process and result. Additionally the method of Task 23 IDP is based on the actors’ individual professional knowledge, which says something about working in praxis when the actors do not carry an interdisciplinary approach. The problems we face in the IDP and in the teamwork are mainly within the communication and understanding of each others professions. A solution to that could be to include a design facilitator (DF) which has the interdisciplinary competences. A DF should have a broad knowledge, understanding and language of both architecture and engineering. A DF should have the overall view of the project and thereby discover unclear issues. For that to succeed it depends a lot on the DF´s qualifications in both architectural and technical aspects. He/she has to have a general understanding of both fields but still sufficiently deep to discover problems or unclear issues for the team members to be able to solve them. An architect trained in using AOD IDP could be a good DF because they know the different approaches and tools and can understand the architectural as well as the engineering language. [Knudstrup 2006]

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The First "Comfort Houses" in Denmark:
Experiences of different design processes

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ABSTRACT: The "Comfort Houses" is the most ambitious building project in passive houses in Denmark until today. Eight single family houses are built and designed by seven different consortiums. Besides fulfilling the German passive house standard the goal was to build the houses according to Danish tradition of architecture and construction. The objective of this research was to clarify the different design processes according to method, tool and teamwork. The processes are evaluated according to the "Integrated Design Process" and the "Traditional Design Process" and show very different take-offs. Analysing the data we can see that: All consortiums agree that it is necessary to work as a team from the early stages of the design process. There is a tendency in all processes that they are not using the tool that are available to document some of the parameters of indoor environment. According to the architectural qualities some of them are often cut back in the process primarily because of cost savings
Keywords: passive house, energy, comfort, integrated design process, praxis, housing

INTRODUCTION

The most ambitious building project in passive houses in Denmark until today is the "Comfort Houses" [1]. It is a 1:1 scale experiment to see if it is possible to build passive houses in a Danish context according to Danish regulations and tradition of architecture and construction. But also to find out if a Danish family likes to live in these houses and to discover which problems and barriers this approach gives in Denmark and on the Danish market. The project was initiated by Saint-Gobain Isover Scandinavia and involved building ten single-family houses as passive houses in the same neighbourhood and constructed by nine different consortiums. The consortiums consist both of architects, engineers, contractors and in some cases also manufactures. The houses are finished and available for sale in autumn 2008. The project has some similarities to the Canadian Equilibrium Housing project [2]

The passive house standard from the Passive House Institute in Darmstadt in Germany is the most acknowledged passive house standard internationally [3]. Thousands of houses have been built in Germany, Austria and Switzerland according to this standard. In Denmark few passive houses have been built in the last 1-2 years, therefore we still need to find our own approach. Besides fulfilling the German passive house standard the "Comfort Houses" should also have a high level of comfort – meaning a good indoor environment according to daylight, acoustic, air quality and thermal comfort. The passive house solutions can not be copied directly from Germany or Austria to Denmark because the requirements to a Danish lifestyle, the traditions in the building industry and the architectural traditions are different. Therefore it is important to find at Danish approach, to get passive houses into the Danish market and thereby minimize the energy consumption in housing.

Figure 1: Overview of the Comfort Houses that fulfils the German passive house standard [1].

It was expressed from the initiators that the consortiums should work integrated with both technical and architectural aspects and work as a team, because many design decisions both affect the energy performance, the indoor environment and the architectural quality of the building. But the initiators did not dictate a methodical approach. In the beginning of the detailing part all consortiums got a fixed budget, which was determined on the basis of the expected market value of the house, and including a small sum to cover the extra cost of constructing a passive house.

The objectives of this research was therefore to clarify the different design processes according to method, tools, teamwork and their approach to achieve architectural quality, to be able to use this knowledge in future projects with passive houses or “Comfort Houses” in Denmark. The results will be based on seven of the finished houses.

METHOD & THEORY

The empirical research of the design processes are analysed trough qualitative focus group interviews of each consortium [4,5]. The interviews are carried out after the semi structured interview method. Each interview is analysed individually and afterwards analysed in a comparative study.

In a design process, especially of low energy buildings, it can be difficult to overview the consequences are of a certain design decision; therefore theoretically the method of the “Integrated Design Process” (IDP) is recommended and there are different approaches available [6,7,8,9,10]. The knowledge from the interviews about the practical experience is compared with different approaches of IDP and the “Traditional Design Process” (TDP) to illustrate which kind of processes the consortiums has had. In the following the TDP and the different approaches of IDP are briefly explained.

The traditional design process (TDP) The description of the TDP is of course a generalisation but it often proceeds like this: The architect and the client agree on the design concept consisting of the form concept, orientation, fenestration and the exterior appearance like characteristics and materials. Then the engineers and consultants are asked to implement or design systems for the building. This procedure is quite simple mainly because the actors in the process are limited and they are implemented linearly, see figure 2. The linear process results in difficulties in optimizing or even impossible to optimize the design according to e.g. energy and indoor environment, because the expertise comes in late in the process. This is a problem especially when designing passive houses where even more parameters are in action than in standard buildings fulfilling the conventional level of performance.

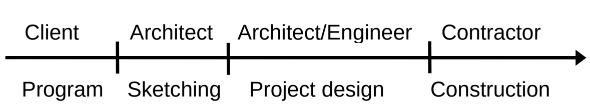

Figure 2: The Traditional Design Process – a linear approach.

The integrated design process (IDP) In the last several years we have seen a lot of different approaches to IDP being developed. Generally they wish to fulfil the same goal but have different visions of aiming. They all focus on the importance of integration of aspects of both engineering and architecture in a holistic synthesis in order to solve the often very complicated problems connected to the design of a building. Although they have the same goal they still vary in some areas: Main parameters in focus in the method, steps and milestones, implementation of actors and their position etc. It often depends on the developer’s main professional interest. Most approaches to IDP have an iterative process as illustrated in figure 3.

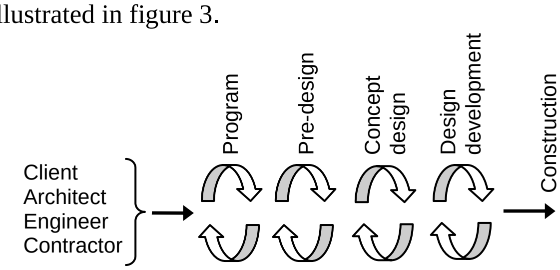

Figure 3: The Integrated Design Process – an iterative linear approach.

Examples of IDP could be:

- International Energy Agency (IEA) Task 23: Optimization of Solar Energy Use in Large Buildings, subtask B (Task 23 IDP) [6]. In this approach the client takes a more active role than usual, the architect is a team leader instead of a sole form-giver and the different engineers, including an energy specialist, takes an active part in the early stages of the process. The process is based on specialist knowledge of each actor. The design develops through iterative operations. The Canadian IDP approach is similar to the model of Task 23 [10].
- The Integrated Design Process, Architecture & Design, Aalborg University (AOD IDP) [7,8]. This approach is developed as a method for architecture students at Aalborg University, Civil Engineering in Architecture & Design. It means it is developed from an architectural point of view. The work is based on the architects design process applying some technical engineering parameters and tools in the programme. All persons carry a new professional interdisciplinary profile that aims at integrating architectural skills and the necessary engineering skills and tools to fulfil the goals.
- Integrated Design of Low- Energy Buildings, Technical University of Denmark (DTU “IDP”) [9]. This approach is one of the newest methods in field and developed from the engineer’s point of view. The procedure in this method is to find the optimal technical solutions in an iterative process between the technical aspects using a tool developed for the purpose. In the end the architectural aspect is incorporated. The question is if the process can be called integrated because the iterative process does not involve the architectural parameters.

THE TEAMWORK

The consortiums agreed in the interviews that the teamwork in this project was different than they were used to, as it usually is based on the TDP. All consortiums talked about the importance of a closer teamwork earlier in the design process and that it is the way forward to be able to make good passive house and low energy building designs in the future. But how they see the teamwork and to what degree the teamwork has been closer, vary in each consortium. The different kinds of teamwork can be classified in three types based on the actors in the TDP and when they are involved.

- Type 1. Incorporated one more actor in the early stages than usual e.g. architect + engineer, but the main influence on the design solution is still from one profession. Later other actors are involved.
- Type 2. Take-off with an interdisciplinary teamwork, but still the design solution is mainly influenced by one or two professions or are based on their premises.
- Type 3. Work as a team together on all aspects of the design e.g. both architect, engineer(s) and contractor from the early stages of the design process.

In the first two types one actor plays a more dominating role than the others and is active from the beginning of the project. Type 3 is based on cooperation between different specialists where all have equal importance. The different types of teamwork are closely connected to the methodical approach of the design processes described in the previous paragraph. It will be further outlined in the next section.

Besides experiencing the need of teamwork between architects, engineers and contractors, the consortiums within type 3 also wanted to bring in the subcontractors earlier in the process because they are specialist of their own products and their knowledge is also important to integrate to be able to design better solutions both aesthetically, functional, technical and economic.

THE APPROACHES TO THE TASK

As mentioned earlier the consortiums were not told to use a certain method in the design process of the houses, and the interviews also showed that all consortiums have worked without a method. Instead they have worked with different strategies. E.g.:

- “Make it simple” as a main guideline
- Outlining a number of focus parameters – some both covering technical and architectural aspects
- ”Trias Energetica” principle [11]
- Performing analysis of consequences of different design solutions
- Or simply designed solutions “on the safe side”.

These strategies are more and less integrated according to the different definitions of IDP. To illustrate the different consortiums approaches to the process individually and compared to each other, their approach are placed on an IDP indicator in figure 4. The scale has in one end the engineering technical approach and in the opposite end the architectural artistic approach. They represent the most extreme ends of how to approach a building design. As a process moves forward often more aspects of other fields is included in the design. In the middle the task 23 IDP is places to illustrating that the architectural and engineering aspects are both covered from the beginning of the process. It means that the figure illustrates the starting point for the project and when the architectural and technical aspects are combined – from the beginning or later in the process, if they are combined at all. The location of the different consortiums approaches are chosen from a) the main actor or cooperation of different actors, b) when and how the actors are positioned in the process and c) the type of focus parameters in each case.

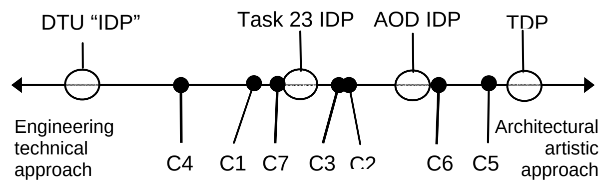

Figure 4: The approaches of the consortiums (Cn) are placed at the IDP indicator. In between them different approaches to building design is placed - the TDP and different approach to IDP which is based on literature study of the different methodical approaches.

The figure shows that the cases are widely spread on the indicator and that the majority of the consortiums have worked very different from the TDP even though they were not introduced to any IDP method. The reason for that might be that the initiators of the project asked the participants to create a consortium and work in teams and share knowledge, even across consortiums. This teamwork must have made some consortiums approach the process more integrated than usual. Maybe they also felt the need to discuss the different aspects to be able to make the right solutions because the concept is new.

The processes have of course not been without problems including the most integrated processes. Consortium 2 has experienced that the boundaries between the professions is more unclear than in a TDP. Even if all actors are present in the discussion and all agree on a decision, it might not be clear who is doing what and when. In consortium 3 they have experienced that even if they have agreed on a certain design aspect, it later turns out that they had different understanding of the same decision because of their different professional traditions. In consortium 1 the team is so focused on the “new” technical engineering aspects that the architect nearly forgets to focus on the architectural qualities of the house. When the architect was asked about which architectural qualities have been important in the design, the answer was that they were closely connected to the energy goals and during the answer the architect became aware that they had nothing to do with architectural qualities and says: *"I do not know what architectural qualities there are in that (the answer). I guess it is more some kind of program parameters."(The architect, consortium 1).* The architect was hypnotized by the quantitative goals and the architectural qualities came in as a second priority.

In consortium 4 the project had so binding constrains that the architect was not able to design good architecture within these. It resulted in architecture, but not as good as it could be. *"Of course you would wish that there had been constructed something … a piece of architecture, right? But because it should express something that both is typical to a Danish standard house, at the same time something that the contractor could bring out to the market and at the same time be the cheapest, then it had a lot of constrains in relation to the architecture … The technical part is the "heaviest" (part) in a single-family house in one storey. I think so as an architect. It means that you do not sit down and sketch by a loose hand. You draw a rectangle and send it to the engineer and ask: ´Is it better now? ´ There is no architecture in that, in principal. ´Should it be a little lower? Arh 20 cm lower ceiling inside´ … It has been a challenge according to think architecture and at the same time think of a passive house in one storey … "(The architect, consortium 4).*

Opposite, in consortium 5, the engineer felt too constrained because the architectural aspects were too fixed. *"I think is was a bit annoying that you in principal sketch a house, and there was not a long time available to do that, and win the competition, wupti! Then you have promised how it should look like, what building services it has and … the cost. Then you are extremely constrained, right? And that is before you have had the time to consider the design, because you have not had the time to calculate and you actually do not know very much (about passive houses). … What was it that we were about to do? We had to learn, but we could not use that for anything because we had promised (how it should look like) … we could have changed a little on the windows ... But we had promised how the house should look like and it is really the architectural idea how the window is placed and turns that direction. Then you cannot change that." (The engineer, consortium 5)*

When the consortiums were asked to mention some recommendations to others in the building industry they pointed out:

- It is important to have a good teamwork early in the design process and work interdisciplinary.
- The teams have to see the design task as a joint mission and that all aspects concern everybody and all have to be enthusiastic about the project.
- The energy aspects have to be integrated into the architectural expression from the beginning of the design process to achieve good solutions. It means we have to work integrated.
- Draw up some guidelines that should be followed in the design process e.g. define main focus parameters both covering architectural and technical parameters.

THE TOOLS

In an IDP it is essential to use some kind of tools to demonstrate that the requirements are fulfilled but also to ensure that the design is moving in the right direction during the process. The tools can be divided into three categories: Architectural, energy use and indoor environment. There is a tendency in which tools the consortiums have used, see table 1.

Table 1: The tendency in which tool the consortiums use during the design process.

Architectural
- AutoCAD - Hand sketches - Some 3D modelling in the sketching phase
Energy consumption
- Be06 in the early stages of the sketching phase (Danish software for calculating energy consumption) - PHPP in the detailing part or in the whole process (Passive House Planning Package [3])
Indoor environment
- Static calculations of the risk of overheating in PHPP. - Other indoor parameters as daylight and noise are not documented by calculations. The solutions are instead chosen according to the experiences from other building.

In other projects they also use the same architectural tools and Be06. But the main difference in this project was that the houses had to be certified as a passive houses and therefore the energy consumption had to be documented by PHPP, which was a new tool for most consortiums. The opinion about the PHPP tool varies, but it has been a challenge for most consortiums to get the needed input data, because the detailing of the design has to be higher than usual e.g. detailed calculation of the specific cold bridges and more detailed data of products. The PHPP tool has been used continuously through the detailing phase to make sure that the project is moving in the rights direction and fulfils the demands. What is interesting is the way PHPP has been used? One way of using the programme is to:

- make at design decision and afterwards check if it is alright with the requirements, if not, redo the design and calculate – "Trial and error"

or

- calculate a reference building and try different changes to that, list the changes and the consequences on the energy use and then discuss what direction to go with the design – "Analysis of consequences"

The latter has been a success for the consortium using this approach and especially a success for the architect, because he/she gets a common understanding of which design decisions has influence on the energy and how much. They also tried to extend the analysis with an economical parameter. Then the contractor also became active. The first approach is instead split up in specialities, one designs and one calculates. Not saying that it can not be successful to use this approach, but the communication becomes an even more important factor in the teamwork.

According to documentation and analysis of the indoor environment, the tools they have used has been very limited. In most consortiums the thermal comfort according to overheating was calculated in PHPP, but the indoor environmental aspects like daylight and noise have in the majority of the cases only been discussed. The design solutions were then based on well known solutions or based on solutions that might accommodate a well known problem. The consortiums know the tools, but they are not used to work with them especially not on single family houses. By not using the tools the problem is that the solutions they select are based on existing building cases. The existing building stock are constructed totally different than the “Comfort House” and therefore they can not be sure it will react the same way e.g. the walls are much thicker than in a standard house and can result in less daylight coming into the rooms and the orientation of the house is much more fixed. Furthermore many of the existing buildings have poor indoor environments and the right solution to the problem could be several. E.g. many complain about acoustics in existing dwellings. If it is not calculated and existing examples are poor, how do we know, when we reach comfort?

THE ARCHITECTURAL QUALITIES

The architectural concept was in all cases defined when handing in the proposal to the competition. Only one consortium changed the whole concept after they qualified for the project but that was a demand from the competition board. In several of the proposals the architectural concept was developed according to passive aspects like compactness, south orientation, passive solar shading etc. Others also worked with a concept of prefabrication or concept of Danish standard housing. It has been investigated if this initial design concept could last through the design process to the final solution or if the consortiums had to make major changes to it to be able to certify the house and/or to construct it within the financial boundaries and in the same time secure a comfortable indoor environment. No major changes had to made to the initial design concept, but some things were changes e.g. the amount or size of windows, the choice of materials, shrinking the size of the house and more. It does not seem to be much but some of the actors think it weakened the architecture. Some changes were made to be able to fulfil the energy requirements and the district plan according to building lines, but most changes were made because of the financial constraints. This illustrates that fulfilling the energy requirements is a smaller challenge than fulfilling the financial requirements. The fact that the economy plays a big part in the level of architectural qualities is closely connected to the fact that architectural qualities are qualitative parameters which can not be transformed into clear definitions and powerful documentation. Therefore architecture has little power in a discussion with other actors in the project [12,13]. It is therefore very important in the beginning of a project to discuss the architectural qualities and maybe use some reference pictures to support a common understanding of this. It is a big job to do so because not even architects necessarily agree on how to understand different qualities. To strengthen the common understanding it is important that all actors care for and are enthusiastic about the project also the contractor. Or else it is hard to open up for new insight which is necessary in order to discuss architectural quality in relation to the other aspects in the project – especially economics. The teamwork between the different professions is also important because it create an ownership to the project for all actors and trough that create an interest in finding good architectural solutions as well.

CONCLUSION

All consortiums state that the future design approach is something different than the TDP – meaning the future design approach take-off differently and create a different cooperation between the actors in the design process. The interviews show that it is not enough for the client to say that the actors have to work closely together from an early stage in the design process, as illustrated by the seven interviews which have shown very different ways of “close cooperation” compared to the TDP. It is therefore important in a design process to define both the teamwork and the methodical approach, as these are closely connected. Therefore if you define a certain type of teamwork you also indicate a certain methodical approach, and vice versa. The interviews show that even in the consortiums where they have worked closely together in an integrated process, they still had some problems mainly about communication and understandings of each others professions.

Some consortiums think it is only in a period they needed to work in an integrated way - until the architect got a better and general understanding of the “new” aspect of building design. But should we go back to letting the architect be the sole form-giver? And let the engineers be the problem-solvers? Do we think it will result in healthier and more sustainable buildings? The risk in IDP is that the architectural qualities are overruled by all the engineering aspects which also were seen in some of the solutions in this project. That is the whole issue of the differences between engineers and architects [7,14]. Architects are generalists and know something about a lot of things e.g. aesthetic, experiences of room, light, materials, everyday life, sociology, psychology and much more. They are trained in combining all these aspects while engineers are specialist and know something about a specific area of the engineering field. Therefore the architect in developing the design is up against integrating several technical quantitative aspects raised by the engineering specialists with his/hers unclear and less well defined qualitative parameters. I think to be able to integrate all the “new” energy and comfort requirements and still design aesthetic and functional buildings in the future, we need to further develop the integrated design approach with a method or a tool to secure architectural qualities in building, especially in low energy buildings and passive houses, where a lot of other aspects are in play.

According to the tools used in this project it is problematic that hardly any tools are used to study or document the indoor environment. That is, as mentioned earlier, a problem because the consortiums do not have the experiences with this kind of houses and do not know the right solutions for sure. Why not do it correctly the first time and use the tools available? People have to live in the houses for more than 50 years.

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Publication 7

The Architectural and Technical Consequences of Different Window Details in a Danish Passive House. Brunsgaard, C. et al. (2008), I Conference Proceedings: 12th International Conference on Passive Houses 2008, Passive House Institute, Darmstadt, Germany pp 375-380.

The architectural and technical consequences of different window details in a Danish passive house

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1 Introduction

In Denmark there are several barriers to overcome before passive houses will spread widely across the country. The project “The Comfort Houses” which involves construction of the first 10 certified single family passive houses in Denmark by 10 different design and construction teams [www.komforthusene.dk] attempts to show that it is possible to build passive houses in Denmark and still respect the Danish building tradition without sacrificing architectural quality.

This paper focuses on a study of window details from “The Comfort Houses” in relation to “traditional” Danish construction solutions. The aim is to evaluate different ways of solving a window detail and to identify both architectural and technical consequences. It is important to investigate both aspects of a detail because the best technical solution might not be the best architectural solution. A proposal from “The Comfort Houses” - a brick passive house, will be used as a basis.

2 Method

The following parameters are used to evaluate architectural expression:

- Spatial and form aspect: scale, proportion, repetition, mass vs. plane, materials etc
- Practical and functional aspect: functionality, layout, light and shadow etc
- Iconographical aspect: style, history and tradition [Bek 1997]

To determine the linear thermal transmittance the simulation tool THERM is used [http://windows.lbl.gov]. The linear thermal transmittance is found by an average value of the losses in the connections in the top, bottom and jambs. The calculations are based on a representative part of the wall construction [EN ISO 10077 - 1 & 2 2006].

3 A traditional Danish brick house

The majority of Danish single family houses are brick houses constructed with cavity walls and many Danes regard brick houses as good quality houses with no maintenance. For the example used in this paper (Brick 1) it has been important to construct a passive house which respects “traditional” Danish brick house style. But what is at “traditional” Danish brick house?

Figure 1: The picture shows an example of a traditional brick house

a (mm)	Ψ (W/mK)
10	0.157
20	0.111
40	0.067
60	0.046
80	0.036
100	0.030
120	0.027

Table 1: The linear thermal transmittance of constructions with different insulation thick-ness between the rebate and wall as illustrated in Figure 3

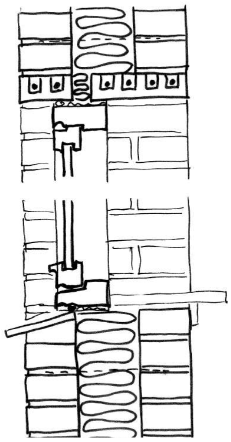


Figure 2: The illustration shows an example of a traditional brick solution. The inner wall thickness is increased along the head and jambs wherein the window is fixed

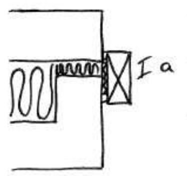


Figure 3: Illustrates the insulation thickness (a) between the rebate and the wall

- Construction, mounting and replacement

The inner wall of a brick construction is normally the load bearing part and it is connected to the outer wall by wall ties with a radius of typically 3-4 mm. The outer wall thickness is often increased along the head and jambs – a window rebate, which constitutes a solid base for fixing and sealing the window [SBI 189 1999]. The insulation thickness between the rebate and wall is typically about 30 mm, if larger it can be difficult to mount the window.

- Architectural expression

The Danish tradition is to place the window outermost in the façade. It gives an architectural expression outside of the wall and window as one surface and the windows only articulate themselves very little. At the same time the tradition and wishes are to have very slender window frames, which give a light and pure expression as well as a less disturbed view to the outside. In most cases the windows open outwards.

- Linear thermal transmittance

The linear thermal transmittance for a construction like that in Fig. 2 is about 0,1 W/mK. By increasing the insulation between the rebate and wall (a) the linear thermal transmittance becomes smaller, as shown in Tab. 1. In a passive house it is recommended to build so-called thermal bridge-free constructions, where the linear thermal transmittance is less than 0.01 W/mK. This means that it is not possible to use the traditional Danish solution shown above as a thermal bridge-free construction. The illustrated example shows in Tab. 1 that it is not possible to lower the linear thermal transmittance to the necessary level without making radical changes to the construction and mounting of the window.

4 A passive Danish brick house

The construction solution in Brick 1 is solved respecting the Danish tradition, but some modifications are made to construct a more energy efficient solution with a smaller linear thermal transmittance. (See details in Fig. 4)

- Construction, mounting and replacement

The wall construction consists of an inner and outer wall of brick, with insulation in between. The wall has an average U-value of 0.1 W/(m²K). To avoid a decrease in the insulation thickness and minimise the linear thermal transmittance, the wall is built without a rebate, unlike the tradition solution. What is special is that the outer wall is displaced compared to the inner wall. The window is fixed to the wall by fittings mounted on the inside of the outer wall. After the fittings have been mounted the window can be installed. At the same time the vapour barrier is taped and jammed between the frame and the inside of the last brick on the top and at the sides. At the bottom it is taped and jammed between the frame and the window sill. It is still possible to mount the window at the inside of the outer wall when both walls are built because the cavity between them is in this case 360 mm, which makes it possible to access the inside of the walls with hands and tools. When the window is put in and fixed to the fittings the remaining insulation can be put into the wall. In the end the vapour barrier is taped to the inside of the inner wall and finally covered with a lining which also jams the vapour barrier to the wall and makes the construction airtight. Later when there is a need to replace the window you have to take off the lining and take the insulation out of the construction around the window to be able to reach the fittings.

- Architectural expression

The idea has been to place the windows as near as possible to the façade, as in the appearance of a traditional brick house, but the linear thermal transmittance had to be better. The solution in this case is to let the brick wall cover the frame. In this way the frame seems more slender from the outside and relates to the traditional slender frames in regular Danish windows, yet it is not possible at the bottom because water has to be led away. The solution results in having windows which open inwards, which is rare in a Danish context. From the inside the full size of the frames will be visible. This will make the view to the outside seem reduced and less clear.

The windows are only slightly marked in the façade as the traditional expression of a brick house. It makes the façade seem like a plane surface. If more windows are placed next to each other the wall still seem uniform because the jump in the façade will be very small. Practically the placement provides more sill space inside, because the passive wall constructions are thicker than usual. It could e.g. be an extension of the kitchen table or become a sitting space if the sill height is low. The placement also result in more passive solar heat gain, because very little overhang will create shadows. When having deep walls as in passive houses the inner finish should be kept in light colours for daylight to reflect into the rooms.

- Linear thermal transmittance

The window is placed in the insulation and results in an average linear thermal transmittance of 0.021 W/mK. This value is greater than the 0.01 W/mK recommended to avoid thermal bridges. Therefore it will be interesting to investigate some variations of the Brick 1 solution. If the linear thermal transmittance is improved, what are the architectural consequences? How will the window be mounted and insulated?

5 Variations of the Brick 1 solution

In countries like Germany, Austria and Switzerland it is common to insulate the frame from the outside and thereby minimize the linear thermal transmittance. The following three variations of the placement of the window in a brick construction will be described and evaluated based on the concept of insulating the frame.

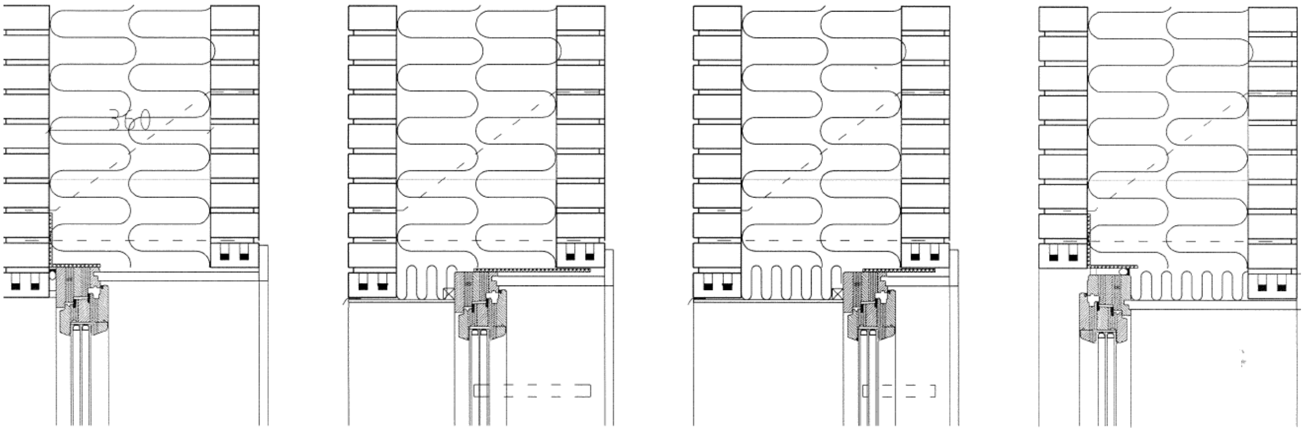


Figure 4: The different construction solutions.

	Brick 1	Brick 2	Brick 3	Brick 4
Placement	**0 mm**	**115 mm**	**230 mm**	**0 mm**
Insulated frame	**No**	**Yes**	**Yes**	**Yes (inside, all around)**
Av. Ψ (W/mK)	**0.020**	**0.009**	**0.008**	**~0.000**

Table 2: The table shows the linear thermal transmittance for different variations of the Brick 1 solution. Av. Ψ is an average value of the linear thermal transmittance around the window and with the fittings (2 %)

- Construction, mounting and replacement

Brick 2: In this solution the window is moved into the middle of the wall. This means that the space between the displaced wall and window frame is filed with insulation and e.g. covered with a fibre cement board. The window is mounted with special developed fittings that are fixed in the window opening of the inner wall (see Fig. 5). The bottom of the window is supported by consoles which are fixed down 3 courses with a threaded bar. The distance for the fitting has a limit of 150 mm, meaning the distance between inner wall and window. The vapour barrier is taped and jammed between the frame and the inner lining. When replacing the window you need to take both linings and insulation in front of the frame out of your construction and put in a new window with fittings.

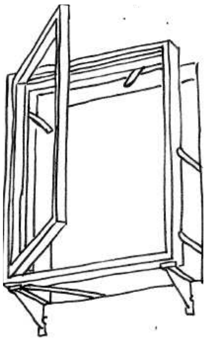
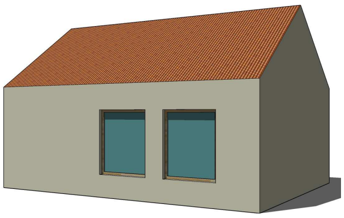


Figure 5:
The drawing illustrates the principle of mounting the window of Brick 2 and Brick 3

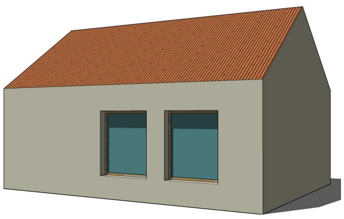
Brick 3: The solution is constructed the same way as Brick 2. The only difference is that the insulation in front of the frame has a greater depth.

Brick 4: As desired in connection to the Danish tradition the windows open outwards in this solution. It means that the frame is insulated inside instead of outside. It also means that the displacement of the walls should be opposite as in Brick 1. The window is mounted and sealed the same way as Brick 1.

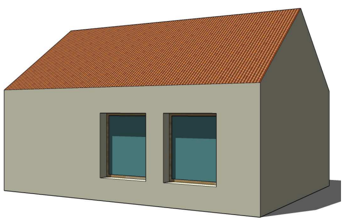
- Architectural expression



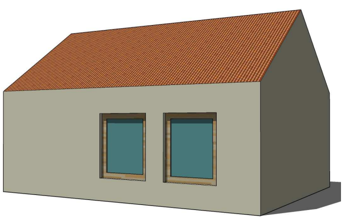
Brick 1



Brick 2



Brick 3



Brick 4

Figure 6:
The illustrations show the principal in the of different architectural expressions

Brick 2: When pulling back the window the wall depth creates shadows on the outer façade which enhance the wall. The depth makes the wall seem more like a mass instead of a surface, or if you repeat the window the wall between them can seem like columns. On the other hand this expression might be weakened by the outer lining which in this case will be made of another material than bricks e.g. fibre cement board. In connection to daylight the colour of the outer lining can also have a big influence on the interior. The depth of the wall can work as solar shading and prevent overheating in summer. A window that is pulled back is more unusual in Denmark, therefore this solution is understood as less Danish and breaks with the traditional expression.

Brick 3: Again as in Brick 2 the shadows that the depth of wall is creating are also in this situation enhancing the wall form outside, and the colour of the outer lining will have even more influence on the daylight conditions inside because it is much deeper. By placing the window so far back in the construction it will have a big influence on the whole expression of the house. It will become a primary feature in the expression, which will be very misplaced in a typology like this – a brick house with saddle roof (see Fig. 6). Windows which are placed very deep create associations with architecture from hotter climates where the need is to keep the heat out, and that is primarily not the case in Denmark.

Brick 4: The only distinction between the expression of Brick 1 and Brick 4 is that the frame is seen as slender from the inside instead of from the outside. It gives you a more undisturbed view to the outside but gives a clumsier expression to the building from outside.

- Linear thermal transmittance

Tab. 2 shows the different calculated linear thermal transmittances. As expected, the more you insulate the frame the smaller the linear thermal transmittance of the solution becomes. Brick 4 has the lowest value because the frame is insulated all the way around and because of the different conductivity of the linings inside and outside in this situation. If one follows the recommendations and makes thermal bridge-free constructions the right solutions for this passive brick house would be to use either Brick 2, Brick 3 or Brick 4, all of which fulfil the value of 0.01 W/mK.

6 Conclusion

It is one thing is to choose the solution with the best linear thermal transmittance, but do any of the solutions fulfil the structural or architectural requirements for the building? That is up to the designer to answer. Should the building express itself as a mass? Is it acceptable to have large frames exposed to the outside? This study has outlined the different consequences, and it shows that the detailing does indeed have a big impact on the whole concept and typology of the building. Therefore it is important to keep this in mind from the beginning of the design process. It is important is to produce solutions which are good both technically and at the same time architecturally, to avoid making bad compromises in the building design.

The author will not dictate what solutions are right or wrong, but maybe the future expression of a passive house might not look like the traditional Danish brick house. Maybe the future has its own architectural style called passive style? Or perhaps we need to develop new products to be able to keep the traditional expression we know, by developing new window designs especially in connection with large window frames. Then the Brick 4 solution could become a good architectural solution.

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Publication 8

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DESIGN RESEARCH EPISTEMOLOGIES I

- Research in Architectural Design

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FORMALITIES

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LIST OF CONTENT

4. Understanding of Danish Passive Houses based on Pilot Project the Comfort Houses

BY CAMILLA BRUNSGAARD

Timeline: 01.08.2007 - 31.07.2010

Keywords: Architecture, Passive houses, Low-energy, Indoor environment, Everyday life, Design processes.

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Biography: Graduated in 2007 at Aalborg University at the Department of Architecture, Design and Media Technology with speciality in Architecture.

Project/chapter	Theory input	Methodology	Epistemology
Understanding of Danish Passive Houses based on Pilot Project the Comfort Houses	Sociology (everyday life), Engineering science, passive house theory, architectural theory	Interviews, measuring/calculations, (and observations, photo documentary, survey)	Empirical-analytical Phenomenology

Introduction & Research question

The building industry in Denmark and the rest of Europe is facing challenges in fulfilling the EU directive of 2002. New buildings and renovation projects need to improve the energy performance to be able to fulfil the Kyoto agreement from 1998 (Directive 2002). In Denmark it has resulted in new building codes according to energy use, which contains a classification of low energy buildings, which will be strengthened the following 5-10 years. By implementing tighter energy demands and energy labelling for existing buildings the awareness of energy performance groves and the energy performance of buildings become a competitive parameter. For the Danish building industry it means that they are facing new challenges both in developing new intelligent and holistic building concepts but also new challenges for the manufacturer of products. Today the build environment accounts for about 40 % of the energy consumption in the EU and it is continuing to expand. It is a result of an effort to give the building users an optimum indoor environment by good ventilation, comfortable temperatures and sufficient light. The level of energy consumption and the quality of the indoor environment in a specific building are very dependent on design and construction of the building envelope. Therefore to be able to fulfil the directive and to protect our environment we need to focus on new building concepts which both generate low energy consumption and a comfortable indoor climate.

In Germany they have build thousands of low energy houses they call passive houses. The concept is now very well acknowledged internationally and many countries are constructing houses that fulfil the passive house standard defined by the Passive House Institute in Darmstadt, Germany (www.passiv.de). In Denmark few certified passive houses have been built in the last 2-3 years, therefore the building industry still need to find its own approach. It is tried through the project THE COMFORT HOUSES (www.komforthusene.dk). Besides fulfilling the German passive house standard THE COMFORT HOUSES should also have a high level of indoor environmental comfort – a parameter that the initiators think appeal more to the Danish population than saving energy. The passive house solutions can not be copied directly from Germany or Austria to Denmark because the requirements from the Danish residents, the traditions in the building industry and the architectural traditions are different. Therefore it is important to find at Danish approach, to get passive houses into the Danish market and thereby minimize the energy consumption in new housing projects. Besides energy savings and new structural solutions also architecture, everyday life and the future ways of living has to be integrated if they should be future-proof and saleable in relation to the buyers and their needs. Therefore knowledge and experience about the architecture, building technique, indoor environment, user behaviour and user needs are studied to reach a more holistic approach.

Figure 1: Overview of the Comfort Houses that fulfils the German passive house standard.

The overall research question is therefore:

What is a Danish passive house seen from the experiences of the Comfort Houses? And what can these experiences enlighten about the future production and use of passive houses?

To answer that the following study fields are examined: *The design process*, *The construction process*, *Architectural expression and building technology*, *Architecture and everyday life and Indoor climate.*

All study fields will be touched upon, but the main focus will be on *The design process*, *Architecture and every day life and Indoor climate.* Therefore following sub-research questions arise:

- **How has the consortiums behind the Comfort Houses approached the design process according to teamwork, method and tools? And what barriers and possibilities lie within the approaches?**
- **How do the residents of the Comfort Houses experience the passive house architecture and the technique? And has their everyday life changed by moving into a passive house?**
- **How do the residents of the Comfort Houses experience the indoor environment and the adjustment of it? And how does is relate to the measured indoor environment? And in what degree do the Comfort Houses live up to a comfortable indoor environment?**

What is meant by architecture? The definition of architecture is generally the art and science to design buildings, rooms or physical structures. In architecture the practical and the aesthetics are inseparable e.g. functions of the house, constructions and materials, spatiality, volume, texture, light and shadow etc. Vitruvius defined before year 1500 architecture to consist of three interrelated terms: *firmitas*, *utilitas* and *venustas*, which can be translated by structural stability, appropriate spatial accommodation and attractive appearance (www.britannica.com). The purpose of this section is not do a thorough explanation or definition of what architecture is, but just to clarify what is meant by *architecture* in this particular context. The aim of this research is to understand the everyday life as it unfolds within the architecture (or the home) – what works well in the house and what does not. And the aim is not to make an extensive architectural analysis of the houses. The Comfort Houses are investigated from the occupants' point of view, since they are the ones who live in the houses everyday and their experiences generate useful knowledge about the life that unfolds in a passive house compared to a "traditional" house. The focus will therefore, in the light of Vitruvius' terms, be on *utilitas* (or translated to appropriate spatial accommodation or functionality) and less on structural stability and beauty, as it will not make sense to investigate the occupants' understanding of the latter as their understandings are on another level than the understanding from the professionals within these fileds. Generally the occupants' horizon of understanding is primarily based on functionality, usability of the house and their life within the house. The occupants are seen as representatives of the target group of this type of houses and they will represent the future occupants or owners of passive houses, therefore it is important to investigate their experience with the outcome of the Comfort House project.

Ideally all above listed study fields should be studied to get a more holistic understanding of passive houses in Denmark, but a limitation is necessary to fit the research within the timeframe (other study field could of course also be included like e.g. economy and politics etc.). Figure 2 shows how the study fields are connected and has an influence on each other. For example first the design process defines what to build and how to build in the construction process. Then the residents move into the houses and create an everyday life. Then as a result the house has an energy use and an indoor environment. It is still believed that it is possible to enlighten how to approach passive houses in Denmark in a holistic way (meaning both focusing on architecture, energy demands and indoor environment of the building so it 'fits together' in a whole) in the future by giving some of the study fields less focus. It is still possible to understand the connection between the design decisions made in the design process and the experience of the architecture and everyday life of the residents without an in-depth analysis of the construction process.

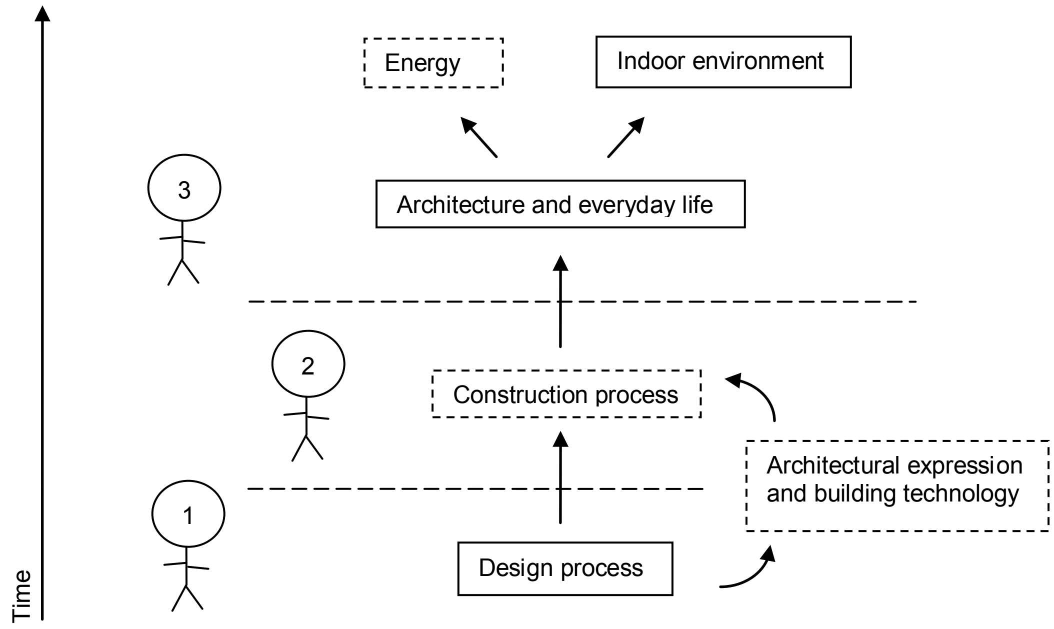

Figure 2: The illustration shows the different study fields and how they linearly take place in time. The matchstick man illustrates how the different fields involve different actors and a need of knowledge transfer.

Methods

The project is based on a case study design. The project consists of ten cases which are THE COMFORT HOUSES and the actors connected to them. The actors are the consortiums that have designed the houses, the craftsmen and the resident in the houses. To be able to achieve a holistic understanding as described above each case will contain more study fields; therefore it can be defined as an *embedded multiple-case* design (Yin 1995).

The first step is to examine each study field in each case and conclude upon them. Then a comparative study of the study fields is made across all cases. Furthermore a comparative study is done across research fields if possible, illustrated in figure 3. In the comparative studies there will be searched for patterns, consistency, new potentials and any dependency between the research fields to be able to develop a holistic understanding of passive houses in Denmark. In each study field different methods is used, both quantitative and qualitative. The quantitative methods are e.g. measurements of the energy use and indoor environment, questionnaires and calculations and simulations of building details. The qualitative methods are e.g. interviews, observations and photo documentation. The methodical approach of this research can be called *mixed methods* (Bryman 2008).

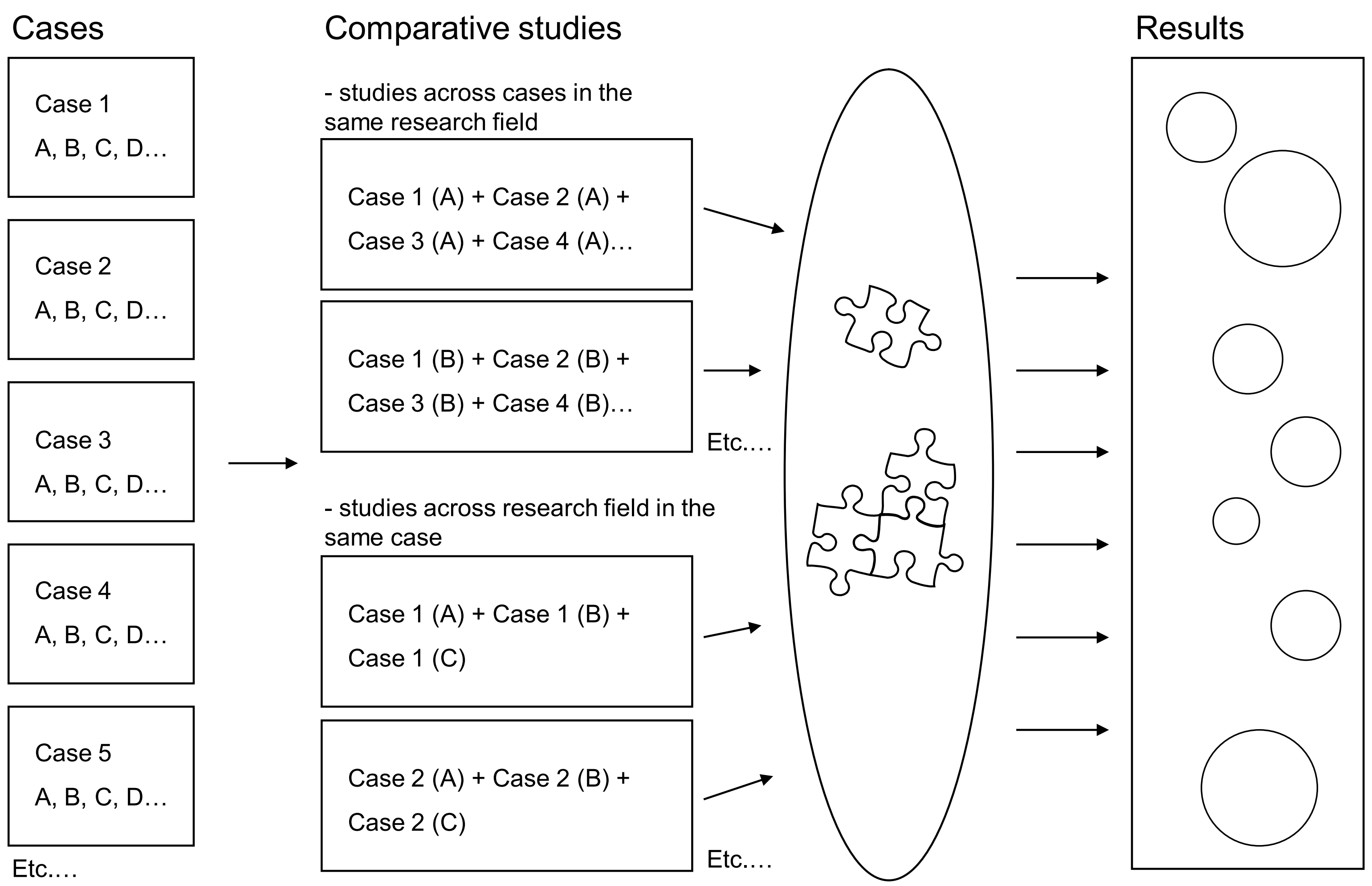

Figure 3. The illustration show how the results are developed through the different cases and research fields in a comparative study. A, B, C, D etc. have to be understood as the different study fields in the project.

Mixed method

Previous some researchers argued that it was not possible to combine qualitative and quantitative methods because a) the embedded methods are not feasible or even desirable. They argue that the two research strategies provide different procedures and therefore different epistemological implications. b) The other argument is that qualitative and quantitative research belong to each there paradigm and according to Kuhn, paradigms are incommensurable. Since the 80´s the argument for combining research has increased. There are areas of overlap and shared aims between qualitative and quantitative research and the paradigmatic war is almost over (Bryman 2008). Looking at e.g. the field of architecture in practice, which works with aesthetic as one of the main aspects, also works with aspects from other professions like engineering, sociology, psychology, politics and more. Some of these professions belong to different paradigms but can easily be combined - or ells architecture would not make sense. Therefore I believe it is necessary in many cases to work with mixed methods, both when you design architecture in practice and when you do research about architecture.

There are different ways in which mixed methods have been carried out, and can be categorised under different terms e.g. *triangulation, completeness, process, different research questions, explanation, illustration, diversity of view etc.* (Bryman 2008). The mixed method in this project can be categorised as *completeness, different research questions and diversity of views* according to the categories in Social Research Methods by Alan Bryman. *Completeness and different research questions* are about using different methods – qualitative and quantitative, because some methods do not provide you with all you need to know or the answers to your research questions, then you have to use more methods to get a more comprehensive view of the research field. These two approaches cover the overall approach of the PhD project, where *Diversity of view* is used as an approach in some of the study fields within the thesis to be cross-disciplinary between engineering and architecture. An example is an investigation of the optimal solutions for how a window is build into a passive house according to the linear thermal transmittance and to the architectural expression of the solution (Brunsgaard 2008). By looking at the research with *Diversity of view* it shows that the best technical solutions is not necessary the best architectural solution. To evaluate different solutions presented in this research you need to switch between quantitative simulations and qualitative subjective experiences of architectural expressions.

Theoretical frame

Overall this PhD. thesis takes off in the passive house standard of the Darmstadt Institute in Germany. This is not a profound theory but the standard is based on international norms and standards which original is based on theories developed from empirical experiments and analysis within natural science. The passive house standard is developed and refined from the late 80´s and consists today of three criteria listed in table 1.

Tabel 1. The passive house criteria (www.passive.de)

Space heat demand	max. 15 kWh/m² per year (net m²)
Primary energy demand	max. 120 kWh/m² per year (net m², incl. household)
Air tightness	max. 0,6 h^{-1} at pressure difference of +/- 50 Pa

The standard also includes a calculation method which is different from other energy calculation methods. This calculations method has to be used to document if a building project fulfils the criteria of a passive house or not. It is also called the passive house *concept*. The passive house concept states that by fulfilling the tree criteria you save the most energy in the building during operation, which makes the concept into a kind of theory to save energy in new buildings. Besides the standard the concepts have some recommendation according to the building design and the technical installations which can be found on the webpage of the Passive House Institute (www.passive.de).

Because of the wide approach in the project it is also necessary to approach the project wide theoretically as well. It means that the theoretical frame changes according to specific research field. In the following I have listed theories that the main study fields draw upon.

The design process

To be able to understand the different design processes behind the ten cases, an insight in different theories in approaching the design process is necessary. Here I have looked at how a traditional design process generally works in practise and different Integrated Design Processes (Brunsgaard 2008). The most central theories are the integrated design process developed by IEA Task 23 Subtask B - Optimisation of Solar Energy Use in Large Buildings – Integrated Design Process Guideline (Löhnert 2003) and as a result of that Mary-Ann

Knudstrup, Architecture & Design at Aalborg University developed a the Integrated Design Processes for problem based learning (Knudstrup 2004). The theory of integrated design states that by working integrated or cross-disciplinary by combining architecture, design, functional aspects, energy consumption, indoor environment, technology, and construction, you eliminate mistakes and bad performing buildings and you end up with a more holistic building design (Löhnert 2003).

Architecture and everyday life

In the analysis of how the passive house architecture influences the resident's *everyday life I use the theories of everyday life and life-modes* (The Danish word "livsform" is translated in Michael Hviid Jacobsen "Encountering the Everyday – an Introduction to the Sociologies of the Unnoticed" to *life-modes*, but others use the word *life-forms* - his paper will use the first). Alfred Schutz (Schutz 2005) and Birte Bech-Jørgensen (Bech-Jørgensen 1997 and 2002) work with the concept of *common sense* which describes a kind of natural attitude which can describe the life - how it seams given and natural. Birthe Bech-Jørgensen states that by using a double perspective you get an understanding of people's everyday life. The everyday life has to be observed from the *conditions* of a certain everyday life (perspective 1) and how the people *manage* the everyday activities (perspective 2), illustrated in figure 4. Birthe Bech-Jørgensen´s research is about the meting between people, but in this research it is more about the meeting between people and the architecture and its technique. Therefore I believe that the architectural design solutions can have an influencing on our behavior in our everyday life. Therefore, besides the demographics, the architecture is a part of the *conditions* to understand the everyday life. Lone Rahbek Christensen has defined three different life-modes of how people relate to their work and free time – *the self-employed*, *the wage earners* and *the career professionals* (Christensen 1994). This theory is included because it offers and alternative perspective and useful tool to categorise lifestyle or everyday life according to the relation between work, family and spare time. The idea is not to use this theory equally to the theories of everyday life, but I will borrow elements that can be useful to understand the everyday life of the residents (I will get back to why it should not stand alone as a theory). The life-modes are seen as a part of the double perspective by Bech-Jørgensen - the *conditions*, to understand people's everyday life in the home, because that contains the family and spare time and sometimes also the work, which the life-modes tell us something about. Some think the theory behind life modes is too ridged, but the idea is not to place people in one category, but it is a theoretical analytical tool and is not found in reality in the society. The theory is also criticised for not taking modernised families into account e.g. dual-career, single parents and division of labour in the home (Jacobsen 2009). This critique will of course be taken into account when labelling the families.

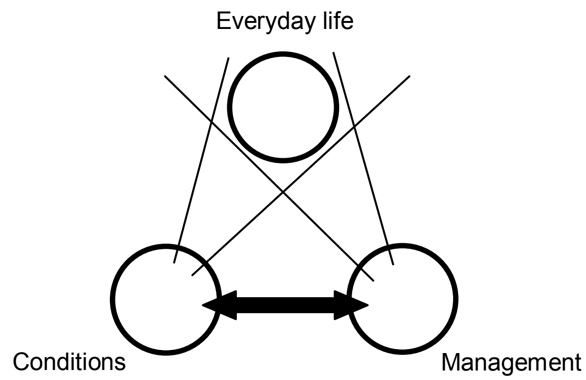

Figure 4. The illustration show the double perspective of Birthe Bech-Jørgensen (Bech-Jørgensen 1997).

The indoor environment and The building technology

Danish and international standards are used to document the indoor environment or to investigate different building details of the houses e.g. CR 1752 (DS/CEN/CR 1752 2001).

The above theories belong to different scientific traditions which will be discussed in the following section

Epistemology

As mentioned above different methods and theories are used in the process of collecting knowledge and experiences from THE COMFORT HOUSES because architecture can be divided into two parts; the measurable and the immeasurable. It means the project both takes qualitative approaches based on subjective sources of information, and quantitative approaches based on objective sources of information. Scientifically these two approaches are founded on two lines in the scientific field: natural science and social science.

Different scientific positions

Natural science is based in the empirical analytical scientific approach and has been dominating since the 1920´ies. At that time there were a clear distinction between objective and factual knowledge on one side and the subjective norms and values on the other side. The clear distinction was later doubted and resulted in different kinds of empirical analytical approaches, but generally empirical analytical scientists are focused on what is positively given and sticks to the verified sayings and refrain from emotions and opinions. The development in the empirical analytical approach today is not so much to set up specific normative instructions for how research should be done, but more to achieve an image of what research is as correct as possible (Andersen 1994). But what is empirical analytical science?

In the empirical analytical field is the object taken out of its natural environment and idealised – it becomes an artefact. It means you will leave out elements which is not relevant to the "experiment". Yet there can still be different ways to outline or define boundaries for an object, not of empirical character but founded in the ontological assumptions. An experiment presupposes a theoretical frame for it to be interpreted and often the ontology lies implicit within it. *Generalisation based on empirical findings* (specific level) or *principals* (general level) can be understood as theories and becomes preconditions for the scientific work. (Kragh 1991)

Social science on the other hand is often more subject orientated and often uses qualitative methods because they are good to discover new fields of knowledge and can tell something about people's motives of actions. In this field we find among many others the phenomenological and the hermeneutical approach. (In the following the discussions will limit to these two approaches of social science, because the goal with this publication is not to describe all scientific approaches). When working with qualitative methods it is important to be aware of what scientific field you place your self in, because they have different ideas of how the human acts, it differs what part the scientist plays and you need different qualitative methods and analysis which also produce different kind of knowledge (Jacobsen 2008).

The phenomenological and hermeneutic approaches both have similarities and differences. They both take off in the individual. An individual that can think, feel and act independently, which thereby influence the social life. These approaches also have in common that they concern about *why* people do, think or act as they do and not just *what* they do. The phenomenological and hermeneutical approaches differ by the way knowledge is understood. It will be described shortly in the following. In hermeneutic you want to understand the part in connection to the whole, meaning that the data have to be understood in connection to the context it is produced in. The data do not speak for it self; it has to be interpreted in its context to make sense. Therefore the researcher itself and his/hers pre-understanding becomes an important part of the findings. In phenomenology the phenomenon is studies on the basis of how the individuals experience reality. The phenomenon does not need to be interpreted but can be described and understood out of how the individual experience them. Therefore the researcher need to step back and be an objective observer and his/hers opinion should not be put in action (Jacobsen 2008).

Scientific position(s) in this Ph.D. thesis

The study fields of this Ph.D. can not be positioned in one scientific position, because they are founded in theories that are based in different scientific positions – eclecticism. In the following the scientific position of each study field will be described and discussed.

The theories behind the passive house standard are based in the empirical analytical field as it is founded in *generalisations based on empirical findings and principals* related to scientific work of indoor environmental and energy engineering. These *principals* is enlighten through national and international standards. That way different "experiments" or in this case calculations of buildings energy use can be produced or reproduced and be compared.

The study of the *architecture and everyday* life wants to find out how the residents experience the architecture of the passive house and want to know if these types of houses affect the everyday life in the house, and in that case how it affects it. A hermeneutic approach would contain an interpretation of the statement (the part) in relation to the context (the whole) to be able to generate insight. An example could be that a resident thinks he feels too exposed in the house because of the big windows to the south. To able to understand why he feels too exposed we need to understand the context. The context could be several e.g. the culture, the society, the background or even the childhood of the resident and more. Additionally the researcher has to take his or hers own pre-understanding into account. In a hermeneutic approach there is not one truth or result, it is more a process where more and more interpretations will cover the field better and better (Jacobsen 2008). The outcome of a statement often leads to more comprehensive description than the original statement (Kvale 1997). In the phenomenological approach on the other hand it is interesting to find out how the phenomenon appear and manifest itself based on how people experience them. Often architecture and the life inside is something you sense and experience and the phenomenological approach will produce knowledge that describes that experience as unprejudiced as possible. Alfred Schutz created with a conceptual universe a phenomenological foundation for how to use everyday life as a basis of the analysis of the social life. The actions that people (or the residents in this case) do in their everyday life on the basis of their consciousness of the everyday life are full of information about how the social life functions and are appointed. Alfred Schutz work with the term inter-subjectivity which is what is common and general for various individuals (Jacobsen 2008). The results are often a condensation of the original statement which still makes sense for the people in their everyday life based on their opinion about their actions (Kvale 1997). Therefore a scientific position in phenomenology would in this study field about the *architecture and everyday life* create knowledge that can be used and understood by other individuals than the ones involved. In this study field the theory about life modes is also involved as mentioned earlier. Life modes are different from the phenomenological inspired everyday life analysis. The life modes were developed by Lone Rahbek Christensen together with Thomas Højrup and were theoretically inspired by structural Marxism and dialectics. The reason is that the research had a different take-off. Thomas Højrups started off by studying the regional planning and legislation and wanted to develop a method to understand the conflicts in the living conditions of different social groups (Jacobsen 2009).

This offset in social formation is fare away from the aim of this thesis; therefore should the theory not be a big part of the theoretical foundation. But as explained earlier, the life modes say something about the family life and the spare time in relation to work – and this relation also has an influence on how they use and live in the house. Therefore I only take element of this theory – the characteristics of the different life modes, and join them with the everyday life theory as described earlier. It means that I will not theoretically touch upon Marxism and dialectic.

By studying the design processes you should at least be aware of what scientific position you, as a researcher, have to the research field, but it is also worth to be aware of what scientific field the artefact you study moves around in.

Let us start to look at the scientific field of the artefact. Two design processes will never be the same and sometimes they actually need to be different – it depends on the project. Each project has individual goals and demand and different design teams have different experiences and knowledge. It means that the theoretical understanding of the design processes do not necessarily take-off in the same theoretical position or balance between theories (knowing that rarely a design process is looked upon theoretically in practice). Looking at the theory behind the integrated design process, it wants to combine both technical and architectural aspect at the same time in the process. The balance between the fields will as mentioned before vary according to the scope of the project – a factory and a dwelling will generally not aim at the same architectural or technical level, but still both fields are in play at the same time. If we look at the traditional design processes, which is a more linear process (Brunsgaard 2009), each scientific understanding takes care of each their field. It means that the design process is looked upon by one set of "glasses" at a time. The scientific approach in the integrated design process is therefore to constantly switch between the empirical analytical and the phenomenological "glasses".

The scientific position I, as a researcher, has to this study field, is to stand on the side and study the artefact – the design process and the constellation of the teamwork. It results in findings of where the different artefacts are positioned according to the different theories of design processes. The results will be unprejudiced descriptions as possible of how the design team experiences the phenomenon – the design process. The scientific position in the research of the design process is phenomenological.

Tabel 2: The theory input, methodology and epistemology of the different study fields in focus in the thesis.

Study fields in focus	Theory input	Methodology	Epistemology
The design process	The traditional and integrated design processes	Interviews	Phenomenological
Architecture and everyday Life	Everyday life theories (Life-modes)	Interviews	Phenomenological
Indoor environment	International standards	Measuring/calculations Interviews	Empirical analytical Phenomenological

The study field about the indoor environment and building technique is originally founded in the empirical analytical field, but we see a bigger and bigger interest in viewing the fields of energy and indoor environment more widely. An example is the PhD thesis of Charlotta Isaksson *"Sustainable learning about indoor heating? – Domesticating energy technology in passive houses"* (Isaksson 2009), which has a sociological approach. She is interested in understanding how the tenants experience and learn to live with energy related technology as a part of their everyday practises. In my thesis I both ask the resident about their experiences and opinions, but also measured the indoor environment. The qualitative and quantitative results are analysed in a comparative study. It is therefore again necessary to use two set of "glasses" – the empirical analytical and the phenomenological.

A thought experiment

Would it make sense and what kind of knowledge would the thesis generate if only one perspective was taken e.g. the empirical analytical? If all research fields were to be looked upon with the same scientific approach, the knowledge produced would without any doubt be different. In the following I will try to make a thought experiment to clarify what will change within the thesis by looking at the three research fields in focus; *the design process*, *architecture* and *everyday life and the indoor environment.*

Let us start with the area of indoor environment were the empirical analytical approach already is in play. The standard of indoor environment forms the basis of the work e.g. CR

1752 (DS/CEN/CR 1752 2001). The outcome tells us *how* the indoor environment is. E.g. 75% of the time the house has temperatures between 20 and 22 ó C and the last 25% it is below 20 ó C. The situation is seen as an isolated object, an artefact, as described earlier. Can the standard give us the answers to why the temperatures are lower in 25% of the time? Maybe if we for example can observe that the window has been open. But the standard cannot tell *why* the window has been open. The researches can have some ideas, but they are based on his/hers previous experiences and not based on empirical scientific work. If the researcher needs to know *why*, he/she has to step out of the observable "experiment" and involve e.g. the occupants, but than the epistemological approach is changing.

To imagine an empirical analytical approach to the research of the design processes can be difficult, because the approaches of social science has become such an incorporated approach for me that anything ells seems wrong. To be able to take an empirical analytical approach it is necessary to look at the design process as an object that can be observed. And that can be difficult in this situation, because the design process has already taken place, so it is only in the participants' memory. How can that be observed as an "experiment"? Are memories and opinions observable? If so how can different opinions of the same experience be taken into account? Etc. These are all questions that needs an answer within an empirical ontology to be empirical analytical. The study field of *architecture and everyday life* will more or less go through the same thoughts. Answers could be to use methods as structured interviews or questionnaires. You will not only have *measures*, like thing you can be counted e.g. age, income and numbers of children, but you have to define *indicator* of different situations which related to the studied (Bryman 2008). But where do those *indicators* come from? Usually it comes from the researchers understanding of the examined – and that is based in the common-sense understanding, which theoretically is founded in social science and not in natural science.

All these thoughts return to were it all begins – the research question. It reflects the scientific approach of the work and what kind of knowledge that comes out of it. If the research question was changed to fully live up to an empirical analytical approach, the idea of the whole research will disappear. As the research question is today it reflects what is needed in the building industry today. And that is more important than what scientific approach is applied as long as the approaches is used "correct".

Summing up on what we just have been through, it shows that to be able to achieve an integrated, holistic understanding for the future development of passive houses both the empirical analytical and the phenomenological positions are necessary. This also fits well with the overall methodical approach – the case study and mixed methods. It is therefore important, during the whole research to be aware of which approach is in play and when to switch. It requires an awareness of method and reflectivity.

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www.komforthusene.dk

Appendix B – Complete publication list

Articles in international journals (peer review)

Brunsgaard, C., Knudstrup, M. & Heiselberg, P. (2010) The Critical Design Process – Experiences from the first “Comfort Houses” in Denmark. I: Architectural and Planning Research. 16 (Submitted)

Brunsgaard, C., Knudstrup, M. & Heiselberg, P. (2010) Occupant Experience of the Everyday life in some of the first Passive Houses in Denmark. I : Housing, Theory and Society. 25 s. (Submitted)

Brunsgaard, C., Larsen, T.S., Knudstrup, M. & Heiselberg, P. (2010) Evaluation of the Indoor Environment in the Comfort Houses - Qualitative and Quantitative Approaches. I: Indoor and Built Environment. 23 s. (Submitted)

Knudstrup, M.-A., Hansen, H. T. R. & Brunsgaard, C. (2009) Approaches to the Design of Sustainable Housing with Low CO2 Emission in Denmark. I : Renewable Energy. 34, 9, s. 2007-2015. 9 s. (Published)

Conference papers (peer review)

Brunsgaard, C., Larsen, T. S., Heiselberg, P. & Knudstrup, M. -A. (2010) Kvantitativ og kvalitativ evaluering af indeklimaet i Komfort Husene. 3rd Nordic Passive House Conference: Towards 2020 - Sustainable Cities and Buildings. 6 s.

Larsen, T. & Brunsgaard, C. (2010) Komforthusene – udvikling af passivhuskonceptet i en dansk kontekst. 3rd Nordic Passive House Conference: Towards 2020 - Sustainable Cities and Buildings. 6 s.

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Internal reports

Brunsgaard, C. (2010) Understanding of Danish Passive Houses based on Pilot Project the Comfort Houses DESIGN RESEARCH EPISTEMOLOGIES I - Research in Architectural Design: Aalborg Universitet : Departmental Working Paper Series, Dept. of Architecture, Design and Media Technology, s. 61-78.

Brunsgaard, C. (2009) Interviewrapport om designprocesserne bag KOMFORT HUSENE. Aalborg Universitet. Institut for Byggeri og Anlæg. 46 s. (DCE Technical Reports; 77).

Brunsgaard, C. (2009) Strengths and Weaknesses of Different Approaches of IDP. Aalborg University. Department of Civil Engineering. 21 s. (DCE Technical Reports; 74).

Other articles/books non scientific

Larsen, T. S. & Brunsgaard, C. (2010) Komfort Husene: erfaringer, viden og inspiration. Saint-Gobain Isover a/s. 259 s.

Brunsgaard, C. (2008) Vinduesplaceringer i passivhuse: ikke så enkelt. I : Glas : glarmesteri, arkitektur, design, teknik. 02, s. 18-21. 4 s.

Appendix C – Tender documents of the pilot project the Comfort Houses

Udbudsmateriale

KOMFORT HUSENE i Skibet ved Vejle

Indbydelse til Danmarks største udviklingsprojekt inden for byggeri uden varmeforsyning.

Udbudsmateriale (begrænset udbud)
KOMFORT HUSENE i Skibet ved Vejle

1. Bygherre
KOMFORT HUSENE A/S
Andkærvej 19
7100 Vejle
mail@zetainvest.dk

I samarbejde med:
Saint-Gobain Isover a/s
Østermarksvej 4
DK-6580 Vamdrup
www.isover.dk

2. Beskrivelse af projektet

KOMFORT HUSENE er et udviklingsprojekt, som omfatter 10 enfamiliehuse baseret på passivhusprincipperne i en samlet bebyggelse i det attraktive Skibet vest for Vejle.

Bag initiativet står Saint-Gobain Isover a/s, ZETA Invest A/S og Middelfart Sparekasse.

Udviklingsprojektet går ud på, at 10 forskellige konsortier/producenter hver opfører ét hus.

Husene skal bygges efter danske byggetraditioner og repræsentere den mangfoldighed, der afspejler fremtidens byggestil.

Målet med udviklingsprojektet er at flytte dansk byggeri ind i verdenseliten for energieffektivt byggeri. Det vil vi gøre ved:

- at indføre begrebet passivhus og dets byggeprincipper i dansk byggeri - med den nytænkning i konstruktioner, det giver,
- at sprede den viden, der opnås under projektet til flest mulige, for generelt at højne byggeriets viden om energirigtigt byggeri, og
- at skabe udviklingsmuligheder for leverandører af komponenter til passivhuse, for eksempel vinduer og ventilationsanlæg.

ISOVER vil stå for undervisning af de prækvalificerede i startfasen og vil være med til at knytte kontakter til leverandører af passivhuskomponenter og danske producenter, der ønsker at deltage aktivt.

Ligeledes vil ISOVER løbende gennem projektet indbyde byggebranchen til workshops om passivhuse og erfaringer fra projektet.

Udviklingsprojektet udbydes ved en begrænset udbudsrunde.

Viljen til at efterleve projektets målsætning samt nedenstående projektkrav vil veje tungt i udvælgelsen af deltagerne.

3. Projektets placering

Udstykningen er placeret på Stenagervænget i Skibet ved Vejle. Materiale over måleblad, koordinatliste, geoteknisk rapport og lokalplan er vedlagt men kan også findes på www.vejlekommune.dk

Grundene i projektet er Stenagervænget nr. 12, 28, 37, 39, 41, 43, 45, 47, 49 og 51. Grundene vil først blive tildelt det enkelte husprojekt efter udbudsrunden.

4. Projektkrav

Nedenstående krav er videreudbyggede i forhold til kravene i prækvalifikationsmaterialet.

Krav til konsortiet/producent:
Konsortiet/producent skal være villigt til at stille egenbetalt udvikling til rådighed for projektet. Den opbyggede viden i projektet skal endvidere stilles til rådighed for byggebranchen og ISOVER, så den kan indgå i et samlet erfaringsgrundlag til videreformidling af passivhusbyggeri til hele byggebranchen.

ISOVER vil gennem hele projektet stå til rådighed og være behjælpelig med eventuelle udviklingsmuligheder, -opgaver, guidelines for beregning samt hjælpe med kontakter til videnscentre, universiteter, erfarne passivhus folk (rådgivere, arkitekter), m.v..

Ligeledes vil ISOVER løbende opsamle den viden som tilegnes i de enkelte projekter, gennem processen. Denne viden vil blive offentliggjort i form af workshops for resten af byggebranchen, gerne i samarbejde med de enkelte husprojekter. Den samlede viden om projektet og passivbyggeri vil efterfølgende blive udgivet i "bogform" og der vil skrives videnskabelige artikler om delemner.

ISOVER ansætter en ErhvervsPhD til samling og evaluering af det samlede erfaringsgrundlag, med speciel fokus på nye konstruktioner og begrebet komfort.

Krav til samarbejde:
Projektets formål er at bygge passivhuse efter danske byggetraditioner. Da der inden for dette område mangler praktisk viden og kunnen, tager projektet udgangspunkt i at tilvejebringe så bred en viden som muligt om passivhuse bygget efter danske traditioner. Dette stiller store krav til samarbejde mellem alle involverede parter i projektet. Ligesom deling af viden vil blive en del af resultatet af projektet.

ISOVER vil gennem projektet indkalde til både individuelle og samlede projektmøder, så der skabes mulighed for at udvikle det enkelte hus, udvikle de 10 huse imellem, udvikle med byggematerialeleverandører, men også for at skabe synergier projekterne imellem.

Krav til huset:
Grundplan
Mangfoldigheden i projektet er vigtig, men samtidig er der tale om en samlet bebyggelse, der skal kunne fremstå som en homogen bebyggelse i moderne arkitektur – bebyggelsen skal afspejle morgendagens huse.

Indretning
Huset skal være funktionelt og udstråle komfort og velvære.
Som et af projektets vigtigste fokusområder skal komforten være i højsæde, derfor skal huset bl.a. indrettes med plankegulv i alle rum på nær i vådrum, for at opnå et optimalt indeklima mht. fodkulde og akustik. Der skal skabes et hus, der fungerer optimalt, hvor rummene er placeret strategisk i forhold til brugen af huset.

Huset skal projekteres til en børnefamilie med to-tre børn, skal indeholde mange og store rum - eventuelt også et rum hvis brug ikke er formålsbestemt.

Huset skal indrettes med carport eller anden overdækket parkeringsplads til min. to biler og redskabsskur.

Klimaskærm

- Væg: U ≤ 0.09 W/m² K
- Loft: U ≤ 0,09 W/m² K
- Gulv: U ≤ 0,12 W/m² K

Kuldebroer skal undgås.

Vinduer skal have en U-værdi på under 0,85 W/m² K inkl. ramme og en g-værdi på 0,5 (samlet energitransmittans).

Alle kravene til klimaskærmen er for til at sikre kravene til energiforbrug, men i høj grad også for at sikre en overfladetemperatur der ikke efterfølgende giver trækgener og lignende.

Klimaskærmen kan udføres som tung ydervæg, let ydervæg eller tung/let kombination.

Lokalplanen stiller krav om 1-planshuse og brug af teglstensmurværk (blank, vandskuret eller pudset). Eventuelle dispensationer fra dette tages op i en samlet helhedsvurdering.
Generelt er bedømmelsen at alternative løsninger, såsom 1½-plan og 2-planshuse, træfacader skal kunne tilpasses kvarteret bedst muligt, hvis der afviges fra lokalplanen.

Alternative energikilder skal integreres i klimaskærmen, så disse ikke skæmmer byggeriet.

Lydkrav
Der skal tages hensyn til bygningens lydmæssige formåen i projektet, så huset fremstår som et komfortabelt hus at leve i efterfølgende. Her skal specielt tages hensyn til de interne lydproblematikker, såsom efterklangstid.

Ved alle konstruktionssamlinger, installationer og gennemføringen skal husets lydmæssige formåen sikres.

Energikrav
Huset skal bygges og fungere som et passivhus.

Huset skal opfylde de krav der stilles til et passivhus

- Energibehov til rumopvarmning: Maks. 15 kWh/m²/år (m² = nettoareal)
- Lufttæthed: Maks. 0,6 h-1
- Varmelast: Maks. 10 W/m² (m² = nettoareal)
- Samlet primært energibehov: Maks. 120 kWh/m²/år (m² = nettoareal)
- Overtemperatur i rum: Maks. 10 %

Energibehovet skal eftervises med ISOVER Energi og PHPP. Programmerne kan erhverves ved hhv. ISOVER og Passivhaus Dienstleistung GmbH.

Inden opstart af byggeriet skal huset kunne certificeres.

Huset skal certificeres af Passivhaus Dienstleistung GmbH, Darmstadt (pris ca. kr. 15.000,-, inkl. beregning og certificering).

Kvalitetssikring
Kvalitetssikring af huset påhviler involverede parter i projektet. Det skal sikres, at huset kan efterleve kravene til et passivhus. Til kvalitetssikringen skal der udføres logbog med medfølgende fotodokumentation.

Husets lufttæthed skal testes og dokumenteres ved hjælp af Blower Door testen.

Krav til tidsplan:
Tidsplanen har to deadlines: Én for råhuset og én for det færdige hus.

- Februar 2008 skal råhuset stå færdig

- August 2008 skal det færdige hus være klar til udstilling og efterfølgende salg

Tidsplanen forventes overholdt.

Krav til økonomi:
Udgifter til grund og tilslutning afholdes af bygherren – KOMFORT HUSENE A/S.

Huset købes af bygherren til kostpris med et aftalt dækningsbidrag, mens den medgåede tid og omkostninger i forbindelse med udvikling af huset med videre står for tilbudsgivers egen regning.

Som i partnering skal der være åbenhed om kostprisen mellem bygherre og entreprenør. Kostpriserne bliver samlet og synliggøres i projektet som generelle tal.

Den samlede tilbudspris skal udspecificeres, og beløb til køkken, hårde hvidevarer, gulvbelægning, maling med videre skal synliggøres.

Udvendig belægning og haveanlæg afholdes af bygherren.

Den aftalte pris ved projektstart skal overholdes.

5. Minimumskrav til tilbud

Tilbuddet skal som minimum - i 3 eksemplarer og som en elektronisk fil - være ledsaget af følgende:

- Generel beskrivelse af hvordan projektkravene tænkes efterlevet, enten som selvstændig beskrivelse eller som et naturligt indhold under et eller flere af nedenstående emner
- Beskrivelse af projektet, herunder valg af hustype, udformning og mulig orientering i forhold til verdenshjørner
- Skitse af huset som tegning, illustration eller visualisering
- Skitseringen skal indeholde grundplan, facade og rumfordeling
- Skitsering af principielle løsninger, herunder både klimaskærm og samlingsdetaljer
- Evt. statiske vurderinger skal følge med
- Eksempler på materialevalg
- Strategi for installationsløsningen
- Foreløbig energiberegning
- Beskrivelse af evt. udviklingsmuligheder, -opgaver i projektet
- Vurdering af om projektet vil kunne efterleve kravene i lokalplanen (kan huset bygges i ét-plan og kan der tilføjes tegl)
- Beskrivelse af økonomiske og tidsmæssige perspektiver og kvalitetsstyring
- Udspecificeret priskalkulation, i henhold til projektkrav
- Garantistillelse fra pengeinstitut eller kautionsselskab om, at der kan udstedes bankgaranti på virksomheden i henhold til AB92

6. Bedømmelseskriterier

Eftersom der er tale om et udviklingsprojekt, vil der i bedømmelseskriterierne blive lagt stor vægt på viljen til at indgå i og samarbejde om et udviklingsprojekt, hvor hele den danske byggebranche vil kunne få glæde af resultaterne.

Ligeledes er det afgørende vigtigt, at konsortie/producent er villig til at bidrage til udviklingen af passivhuskonceptet, så det kan tilpasses dansk byggetradition, og at konsortie/producent er villig til at tage del i en større selvfinansieret egenudvikling.

Viljen til at samarbejde med andre aktører inden for og uden for projektet vil ligeledes tælle meget. Ligesom det er vigtigt for projektet, at der gennem hele forløbet er en åbenhed om erfaringer og resultater.

Kriterier for vurdering af projekter:
Ovennævnte minimumskrav samt villigheden til tværgående samarbejde, udvikling og åbenhed, vil danne baggrund for vurderingen af det enkelte husprojekt.

Kriterier for udvælgelse af deltagere:
For udvælgelsen af de 10 projekter vil kriterierne være en samlet vurdering af nedenstående punkter, punkterne er ikke prioriteret:

- Overholdelse af projektkrav, herunder løsning af den tekniske komfort i bygningen
- Æstetik og anvendelse
- Bygbarhed, materialevalg, miljøvenlighed og udviklingsmuligheder
- Vurdering af om huset vil kunne certificeres
- Pris og estimering af vedligeholdelsesomkostninger over 10 år

Dernæst vil kompetencer og overholdelse af tidsplan og økonomi veje tungt.

7. Bedømmelseskomité

Bedømmelsen foretages af KOMFORT HUSENE A/S og Saint-Gobain Isover a/s samt eksterne repræsentanter.

KOMFORT HUSENE A/S:
Claus Moser, underdirektør, Middelfart Sparekasse
Tue Hattens, stat. ejendomsmægler MDE, et godt HJEM A/S
Mogens Zinck, direktør, ZETA Invest, investor og udvikler af fast ejendom
Thomas Nitz, direktør, ZETA Invest, investor og udvikler af fast ejendom

Saint-Gobain Isover a/s:
Susanne Højholt, udviklingschef og projektleder for KOMFORT HUSENE
Erling Jessen, skandinavisk innovations- og tekniskchef
Jan Riis Nielsen, salgs- og marketingdirektør
Charlotte Højmark, know house, beregner i PHPP og ISOVER Energi

Aalborg Universitet:
Fagrepræsentant
ErhvervsPhD

Fagdommer

Ved bedømmelsen vil Vejle Kommune endvidere være repræsenteret.

8. Procedure

Projektet udbydes ved en begrænset udbudsrunde.
Der er 20 prækvalificerede deltagere til den afgørende udbudsrunde, hvoraf der skal findes 10 projekter.

Tilbuddet skal være Saint-Gobain Isover a/s i hænde **senest 11. juni 2007** på adressen:

Saint-Gobain Isover a/s
Østermarksvej 4
6580 Vamdrup
Att. Susanne Højholt

Tilbuddet skal sendes i 3 eksemplarer og som en elektronisk fil. Den elektroniske fil kan sendes som CD eller til e-mail-adressen: KOMFORTHUSENE@isover.dk

Nærmere oplysninger kan fås ved henvendelse til Susanne Højholt, tlf.: 72 17 17 17

Nærmere dokumentation kan fås ved henvendelse til KOMFORTHUSENE@isover.dk

Den 13., 14. og 15. juni indbydes der til en individuel fremlæggelse af tilbuddet. Fremlæggelsen vil foregå i Middelfart og der vil blive udsendt en tidsplan senere i forløbet.

Udgifter i forbindelse med udbudsrunden honoreres ikke.

9. Andre oplysninger

De 10 udvalgte projekter offentliggøres **senest den 27. juni 2007.** De udvalgte projekter får direkte besked. Offentliggørelsen vil foregå ved udsendelse af pressemeddelelse, orientering på Isovers og KOMFORT HUSENE's hjemmeside samt udgivelse af projektmateriale med skitse af de enkelte konsortier/producenter og deres projekter.

Alle 20 projekter offentliggøres i en samlet publikation i 3. kvartal 2007.

Købskontrakt med hvert enkelt husprojekt udarbejdes umiddelbart efter udvælgelsen.

Grundene tildeles hvert enkelt husprojekt, efter en samlet vurdering af projekterne, dette vil ske i samarbejde med Vejle Kommune, hvor eventuelle dispensationer også vil afklares. Tildelingen vil ligeledes ske umiddelbar efter udvælgelsen.

Vejle Kommune er varslet, at der i august/september 2007 indleveres ansøgning om byggetilladelse på de 10 passivhuse.

Det videre forløb
Efter udvælgelse af de 10 projekter indbydes til opstartsmøde, og i august inviteres til en 2-dages workshop, hvor beregninger og detaljer gennemgås med deltagelse af Passivhaus Instituttet, Darmstadt.

Derudover inviteres der til projektmøder igennem projekterings- og byggeprocessen.

10. Vedlagt materiale

Følgende materiale er vedlagt:
- Udbudsmateriale
- Måleblad
- Koordinatliste
- Geoteknisk rapport
- Lokalplan
- ISOVER Multi Comfort House (engelsk udgave)

KOMFORT HUSENE

KOMFORT HUSENE

Et samarbejde mellem:

ZETA INVEST

MIDDELFART SPAREKASSE
- vi har overskud til dig

ISOVER

Appendix D – Question guide of the interviews

App. D.1 The Design Process

The following question guide (in Danish) is used during the data collection to the analysis of the design processes behind the Comfort Houses. This guide has been the foundation to all interviews, but the individual interview has had additional questions because of clarification and elaboration etc.

Spørgeramme
1.0 Indledende spørgsmål: 1.1 Har I arbejdet sammen før? 1.2 Hvordan fandt I sammen i konsortiet? 1.3 Hvorfor ville I gerne være med i projektet, KOMFORTHUSENE? 1.4 Hvilket kendskab havde I til det at lave energioptimerede eller lavenergi huse før projektet, altså før den første workshop? 1.5 Vil en af jer starte med at lave et kort oprids af jeres proces? Opstart, tilbud, workshops.
2.0 Problemstillinger: De største problemstillinger 2.1Kan I beskrive nogle af de største problemstillinger I havde i processen og hvordan de blev løst? Husk problemstillinger fra workshops.
3.0 Metode: Tværfaglig integreret proces eller en traditionel lineær proces. Valg af metode til at styre procesforløbet. 3.1 Har designprocessen været en anderledes proces end den plejer? Hvis ja, hvad er det, som har gjort den anderledes? Har I haft lige så mange møder og de

samme diskussioner som I plejer?

3.2 Hvad var vigtigt for jer, da I skulle planlægge projektforløbet? Faste møder, bestemt rollefordeling, fastsættelse af deadlines eller delmål?

3.3 Havde I flere designkoncepter i spil på en gang?

3.4 Hvis ja, hvordan blev det enkelte designkoncept vurderet og det endelige valgt? Hvad var udslagsgivende for valget?

4.0 Værktøjer: Anvendt og implementeret, både design- og beregningsmæssigt?

4.1 Hvordan blev de arkitektoniske idéer visualiseret og kommunikeret gennem processen?

4.2 Hvordan sikrede I at overholde de energimæssige krav? Hvordan og hvornår i processen blev det eftervist?

4.3 Hvordan blev det kommunikeret i konsortiet?

4.4 Hvis de nævner Be06 og PHPP: Hvornår brugte I det og det andet program? Levede begge programmer op til jeres behov?

4.5 Hvordan og hvornår i processen vurderede I at komforten var tilfredsstillende opfyldt?

4.6 Hvis de har brugt erfaringer fra andre projekter: Er der komfort i de huset i tænker på? Hvad er komfort for jer?

4.7 Hvordan blev det kommunikeret i konsortiet?

4.8 Evt. stille direkte spørgsmål til hvilke værktøjer, hvis ikke de allerede er nævnt? Specielt til komfortværktøjer.

5.0 Samarbejdet: Hvilket samarbejde har der været i projekt?

5.1 Hvordan oplever I jeres samarbejdet har været?

5.2 Har samarbejdet været anderledes end den plejer?

5.3 Hvis ja, hvad er det der har gjort det anderledes?

5.4 Hvordan har forståelsen været for hinandens fagligheder?

6.0 Arkitektur og formsprog:

6.1 Hvornår vil I vurdere at det arkitektoniske hovedkoncept blev fastlagt? Et godt tidspunkt i processen?

6.2 Er der sket væsentlige arkitektoniske ændringer fra tilbudet til færdigt byggeri?

6.3 Hvis ja, hvornår lå det i forløbet? Hvilke og hvad har ligget til grund for ændringerne?

6.4 Hvilke arkitektoniske kvaliteter har I lagt vægt på i designet?

6.5 Hvilke steder i beslutningsprocessen, træffes der valg om disse aspekter?

Uddybende spørgsmål til arkitektonisk kvalitet, checkliste.

6.8 Hvilke tanker ligger til grund for det hovedkoncept (helheden) der er valgt for huset?

6.9 Hvilke hensyn er taget til f.eks. funktionalitet, brugskvalitet, materialer?

6.10 Hvilke overvejelser har der været for lys og udblik i boligen?

6.11 Hvilke overvejelser har der været i forhold til stedet og beliggenheden?

6.7 Er der noget som I har måttet gå på kompromis med eller noget I bestemt ikke ville gå på kompromis med?

7.0 Opfattelse af fremtidige tilgange til design af passivhuse/ lavenergi byggeri

7.1 Kan I nævne nogle vigtige erfaringer I har gjort jer i forhold til designprocessen bag passivhuse? Hvad er de gode og dårlige erfaringer?

7.2 Vil de nævnte erfaringer få betydning for jeres fremtidige designprocesser i forhold til passivhus/ lavenergiprojekter? Hvordan?

7.3 Kunne I have gjort noget for at optimere processen?

7.4 Har I nogen anbefalinger til andre rådgivere, som gerne vil i gang med passivhuse/ lavenergihuse? Eller noget man skal være specielt opmærksom på i processen?

7.5 Har I evt. idéer til ting der mangler som kunne lette processen? Nye metoder eller værktøjer?

8.0 Afslutning

8.1 Er der her nogle elementer/emner I synes der mangler at blive berørt? Eller afsluttende bemærkninger?

App. D.2 The Everyday life and Indoor Environment

The following question guide (in Danish) was used in the data collection for the analysis of both the everyday life in the Comfort Houses and the occupants' experience of the indoor environment. The interview was divided in two sections with minimum a half year in between. The first interview was about their everyday life and experience of the indoor environment in their previous home and the second interview was about the life and experience in the new home – the Comfort House. Then it was possible to compare now and before they moved in.

Spørgeguide

Interview 1

Intro - Baggrundsinformation

Jeg vil starte med et par generelle spørgsmål omkring din/jeres familie- og arbejdssituation og lidt om jeres familiebaggrund.

1. Hvor er du/I vokset op? (stilles kun hvis personen muligvis ikke er vokset op i DK)
2. Hvor boede i før I flytte ind her?
3. Hvor mange er du/I i husstanden? Vokse og børn? Alder på børn?
    - Har I husdyr?
4. Kan en af jer kort beskrive jeres bolig- eller flyttehistorie?
5. Kan du/I sige noget om den type bolig(er) du/I er vokset op i? Hus, lejlighed, ejer/lejer?
    - Hvilken boligtype vil du allerhelst bo i? Hvorfor/hvorfor ikke?
6. Kan du/I beskrive hvad dit arbejde består i?
    - Hvor mange timer arbejder du/I ca. om ugen?
    - Glad for dit arbejde?
7. Hvad betyder arbejdet for dig/jer?
    - Er det afgørende at være selvstændig erhvervsdrivende?
    - Er arbejdet et middel til at tjene en anstændig løn, så du kan leve dit liv efter fyraften?
    - Eller er det vigtigt for dig at skabe udfordringer på arbejde?
8. Hvad betyder din fritid for dig/jer?
    - Tidsopfattelse er ikke splittet op i arbejde og fritid, men smelter sammen i et dagsværk.
    - Kan du finde på at tage arbejde med hjem eller tænker du sjældent på arbejde?
    - Bruger du din fritid til at koble fra og lade op til dit arbejdet op? Hvordan lader du op? Gennem baglandet?

9. Føler du/I at du/I har de tid nok? Hvad ville du/I bruge 10 timer til, hvis du/I fik dem foræret? (børn, samvær, bolig, uddannelse, dit job, sig selv etc. Eller lidt af hvert?
10. Hvilken beskæftigelse har/havde jeres forældre?

Arkitektur – tidligere bolig

Jeg vil gå videre til at spørge ind til din/jeres tidligere bolig og jeg vil starte med at snakke om arkitekturen.

Generelt:

11. Hvilken type bolig boede du/I i før dette hus?
    - Ved du/I hvornår det var fra?
    - Hvilket kvarter eller boligområde lå den i?
12. Kan du prøve at fortælle mig om hvordan din tidligere bolig så ud, så jeg kan danne mig et billede af den? Størrelse, rumhøjde, antal værelser, disponeringen af rum, materialer, udearealer etc.
13. Var det vigtigt for dig/jer hvilket udtryk boligen havde set ude fra? ?
    - Hvis ja hvilke faktorer? Materiale, stil, størrelse etc.?
14. Var det vigtigt for dig/jer hvordan boligen så ud indefra?
    - Hvis ja hvilke faktorer? Materialer, stil, farver, rumhøjde, åbne rum/lukkede rum, køkkeninventar etc.? (Funktionalitet, visuelt udtryk)

Funktionalitet:

15. Opfyldte boligen dine/jeres behov? Hvis ikke, hvorfor?
16. Var boligen godt indrettet? Brug gerne eksempler som underbygning eller tegn og fortæl.
    - Hvad fungerede godt og hvad fungerede mindre godt?
    - Var rummenes størrelser ok?
    - Hvordan brugte du/I de forskellige rum? Lå de godt i forhold til hinanden? Hvad betød det for dit/jeres dagligdag? Praktisk, anvendeligt, fleksibelt, isolerende etc.
    - Var der mangler i boligen? Evt. hvilke?

Lys og udkig:

17. Hvordan oplevede du/I dagslyset i forhold til boligens rum?
    - Var der dagslys nok eller brugte du/I kunstig belysning?
    - Hvordan var din/jeres sansmæssige oplevelse af dagslyset? Var det nogen tidspunkter, hvor lyset specielt påvirkede dig/jer? Kan du/I beskrive det?
18. Hvad syntes du/I om de udkig I havde fra boligen? Kan du/I beskrive hvad du/I så?
19. Havde lys og udkig nogen betydning for møbleringen af boligen? Hvis ja, hvilken?

Materialer:

20. Hvilke materialer var der anvendt i den tidligere bolig?
    - Hvad synes du om materialevalget?
    - Farverne?

Æstetik:

21. Hvordan udtrykte boligen sig overfor dig/jer?
    - Hvilke sanseoplevelser var der forbundet med huset?
    - Var det et smukt eller dejligt hus/lejlighed og hvorfor?

Udearealer:

22. Hvordan var adgangen til udearealer? Hvad var godt og mindre godt, hvorfor?
23. Hvad syntes du/I om anvendeligheden af udearealerne? Sol-skyggeforhold, læ og sanser etc.
    - Hvordan brugte du/I udearealerne? Leg, spisning, afslapning
    - Kunne du/familielivet udfolde sig her etc.

Energi

Jeg vil fortsætte med at høre lidt om jeres holdning til energi og indeklima i den tidligere bolig.

24. Hvilken type opvarmning havde du/I i den tidligere bolig?
25. Var du/I optaget af at passe på miljøet og energiressourcerne? Hvorfor/hvorfor ikke?
26. Var du/I optaget af at spare på energien i boligen? Hvorfor/hvorfor ikke?
    - Fulgte du/I med i hvor meget din/jeres el, vand og varmeregning var på i din/jeres tidligere bolig?
    - Kan jeg få en kopi af jeres opgørelser?
    - Var det noget i fx diskuterede, om der kunne spares på energiforbruget?
    - Hvis ja. Hvilke overvejelser har I gjort jer? Sparepærer, hvor mange?
    - Gennemførte du/I nogen af disse overvejelser?
27. Når/hvis du/I sparer, er det så pga. miljøet og energiressourcerne eller økonomien eller begge dele?

Indeklima

28. Kan du/I beskrive hvad et godt indeklima er for dig/jer? Evt. give dem nogle stikord. Hvad med…(temperatur, lyd, lys og luft)
29. Var det vigtigt for dig at der var et godt indeklima i den tidligere bolig?
30. Hvad syntes du om indeklimakomforten i den tidligere bolig? Kan du/I fortælle om en eller flere situationer, hvor du/I ikke var tilfreds med indeklimaet? (fx træk, kuldefald ved ydervægge, koldt ved gulvet, tør luft).
    - Gjorde du/I noget ved det? I så fald hvad?

Temperatur:

31. Kunne du holde varmen i den tidligere bolig?
    - Var der problemer med træk? Hvis ja, hvorfra og hvilken betydning havde det for dig/jer? Bestemt møblering, undgik ophold i zonen, forsatsruder etc.
    - Var det fodkoldt
32. Havde du/I problemer med at der var for varmt i boligen? Ofte?

Luftkvalitet (luftfugtighed):

33. Hvordan var luftkvaliteten? Tør, fugtig, dårlig lugt, tæt, tung?
    - Havde I naturlig eller mekaniske ventilation? Badeværelset?
    - Hvordan og hvor ofte luftede du/I ud?
    - Slukkede du for varmen samtidig?

Lyd:

34. Kan du beskrive hvordan du oplevede lydforholdene i den tidligere bolig? Ok, alm. rungende, død?

Aktivitetsmønstre

Jeg vil nu bevæge mig over til at høre lidt om hvordan din/jeres hverdag så ud i den tidligere bolig. Formålet er at få et billede af jeres hverdagsliv for at have noget at sammenligne med i forhold det nye hus.

35. Hvad gjorde du/I på en helt almindelig dag fra du/i står op til du/i går i seng? Husk begrundelser!
    - Hvad fortog du/i dig/jer? Vi kan starte med morgenen…
    - Hvad er det første du gør, når du står op om morgenen?
    - Hvad er det sidste 3-4 ting du gjorde inden du tog af sted om morgenen/ på arbejde?
    - Hvad er det første du gør når du kommer hjem om eftermiddagen? Og derefter?
    - Hvilke aktiviteter foregik der (madlavning, tøjvask, gæster, besøger venner, hobbyarbejde, sport, læser, tv/dvd/pc, ude i byen, på udstillinger, i naturen osv.)?
    - Hvordan omgår du/I vennerne? Inviterer, uanmeldt, arbejdsrelateret, ude i byen, venner fra forening/klub etc.
    - Hvad sker der om aftenen? Hvem gør hvad, sammen/individuelt? Hvor og hvorfor der?
    - Gør i noget bestemt hver dag inden i går i seng om aftenen?
    - Hvordan er temperaturen i soveværelset? Hvorfor?
    - Hvis de har åbne vinduer om natten, er det så pga. frisk luft eller lavere temperatur?

Forventninger og bevæggrunde

Nu vil jeg afslutningsvis spørge lidt ind til de forventninger, som du/I har til den nye bolig.

36. Hvilke forventninger har du/I til det nye hus her?

- Arkitekturen: Hvad tiltaler dig især ved det nye hus? Eller hvad glæder du dig især over at skulle til at bruge i huset?
- Energiforbrug og indeklima: forbrug, varme, kulde, luftkvaliteten i boligen

37. Hvordan fandt du/I frem til at du/I skulle flytte ind i dette hus?

- Overvejede du/I nogle af de andre huse i området? Hvad afgjorde dit/jeres valg?
- Hvorfor flyttede du fra den tidligere bolig?

Interview 2

Intro, small talk

Vi har måske været inde på nogle ting i sidst interview, men du nævner det bare igen.

1. Hvad synes du om at bo i Danmark? (Stilles kun hvis beboerne ikke er vokset op i Danmark)
2. Er I faldet godt på plads herude i Skibet?
3. Er husstandssammensætning den samme som ved sidst interview?

Arkitektur

Jeg vil starte med at spørge ind til hvad du/I synes om boligens arkitektur og brugen af den.

Generelt:

4. Lever boligen op til dine/jeres forventninger?
    - Er der noget du/I især har tænkt på der er godt eller skidt ved huset her?
    - Er der mangler i boligen? Evt. hvilke?
    - Føler du/I at du/I har været nød til gå på kompromis med noget?

Funktionalitet:

5. Hvad synes du/I om boligens indretning?
    - Hvad fungerer godt og hvad fungerer mindre godt?
    - Hvordan bruger I de enkelte rum? Ligger de godt i forhold til hinanden? Hvad betyder det for jeres hverdag? Praktisk, anvendeligt, fleksibelt, isolerende, kompakthed, barriere (etager)etc.
    - Hvilke rum fungerer godt og mindre godt, og hvorfor?
    - Hvad synes du/I om rummenes størrelse?
    - Opfylder boligen dine/jeres behov? Eller har den mangler? Hvilke?
    - Hvordan fungerer det med de dybe lysninger? Er det noget I har tænkt over under indretningen?
    - Betyder husets indretning noget for jeres familieliv f.eks. gør I ting mere/ mindre eller anderledes i Komfort Huset?
6. Har du/I et favoritsted i huset? Hvad er det, som gør det til et favoritsted?

Lys og udkig:

7. Hvordan oplever du/I dagslyset i boligen?
    - Er der dagslys nok? Også på værelserne? Tænder du den kunstige belysning når du går ind i et rum? Hvilke rum? Vane eller har du behov for mere lys?
    - Hvordan er din/jeres sanselige oplevelse af dagslyset? Er der nogen tidspunkter, hvor lyset specielt påvirker dig/jer? Kan du/I beskrive det?

- Bruger i skodderne/ solafskærmningen eller fungere udhænget godt i forhold til lyset midt på sommeren? Hvornår og hvorfor?

8. Hvad synes du/I om de udkig du/I har fra boligen?
    - Vil du gerne have haft andre eller flere udkig og hvorfor? (udkig mod nord)
    - Oplever I nogen gener med placeringen af vinduerne?
    - Hvad synes du/I om den måde vinduerne er konstrueret og fungere på i forhold til traditionelle vinduer? Åbner indad? Tykkere?
    - Hvordan oplevet det at være i huset når der er mørkt?
9. Havde lys og udkig nogen betydning for møbleringen af boligen? Hvis ja, hvilke? Lyset, solen, indkig fra nabo eller vej etc.

Materialer:

10. Hvad synes du/I om de materialer boligen er lavet af?
    - Er der nogen materialer som du gerne vil erstatte med nogle andre hvis du kunne? Hvorfor? Vedligehold, sanser.
    - Farver?

Æstetik:

11. Hvordan udtrykker boligen sig overfor dig/jer?
    - Hvilke sanseoplevelser forbinder I med huset?
    - Er det et smukt og dejligt hus?

Udearealer:

12. Hvordan fungerer adgangen til udearealerne?
    - Er der let adgang til at bruge fx terrassen og fx spise ude om sommeren? Hænger de godt sammen med boligen?
    - Hvad er godt og mindre godt?
13. Hvad synes du/I om anvendeligheden af udearealerne? Sol- og skyggeforhold, læ og sanser etc.
    - Hvordan bruger du/I udearealerne? Leg, spisning, afslapning etc.

Stedet og beliggenhed:

14. Hvad synes du om stedet og beliggenheden af boligen?
    - Både på grunden, i området og orienteringen?

Holdninger og værdier til arkitektur

15. Er det vigtigt for dig/jer hvilket udtryk boligen har set ude fra?
    - Hvis ja hvilke faktorer? Materiale, stil, størrelse etc.? Og hvorfor?
16. Er det vigtigt for dig/jer hvordan boligen ser ud indefra?
    - Hvis ja hvilke faktorer? Materialer, stil, farver, rumhøjde, åbne rum/lukkede rum, køkkeninventar etc.? Og hvorfor?

Energi

Jeg vil fortsætte med at høre lidt om jeres holdning til energi og indeklima.

17. Er du/I i dag mere optaget af at passe på miljøet og energiressourcerne? Hvorfor/hvorfor ikke?
18. Er du/I i dag mere bevidst om at spare på energien i boligen?
    - Følger du/I med i hvor meget energi du/I bruger i huset?
19. Diskuterer I, om der kan spares på energiforbruget i boligen? Og hvilke overvejelser har I gjort jer?
    - Gennemfører du/I nogen af disse overvejelser?
20. Når/hvis du/I sparer, er det så pga. miljøet og energiressourcerne eller økonomien eller begge dele?
21. Er det komfortable for dig/jer at leve med de energispare tiltag der er lavet i boligen? Eller er det noget som du/I synes burde være lavet anderledes?
22. Udover det huset er installeret med, bruger du/I så energispare pærer og energispare skinner til det elektroniske udstyr?

Indeklima

23. Er det vigtigt for dig/jer at der er et godt indeklima i boligen?
24. Kan du/I beskrive hvad et godt indeklima er for dig/jer? Giv evt. stikord. Hvad med…(temperatur, lyd, lys og luft)
25. Hvad synes du om indeklimakomforten i boligen? Kan du/I fortælle om en eller flere situationer, hvor du/I er utilfreds med indeklimaet? (fx træk, kuldefald ved ydervægge, koldt ved gulvet, tør luft).
    - Gjorde du/I noget ved det? I så fald hvad?

Temperatur og træk:

26. Kan I holde varmen? Hvad gør I hvis ikke I kan? (En trøje på, skuer op for varmen på anlægget)
    - Er der problemer med træk?
    - Er der fodkoldt?
    - Kan du mærke gulvvarmen på badeværelset?
27. Oplever I at der kan være for varmt i boligen? Hvad gør I for at undgå eller løse det? Åbner vinduerne, by-pass i ventilationen, trækker du solafskæmningen for? Hvornår trækkes solafskærmningen fra igen?
28. Opholder/møblere du dig andre steder i huset end du plejer i forhold til det gamle, hvis man tænker på indeklimakomforten?
    - F.eks. tæt på vinduerne? Ingen træk/kuldenedfald, godt dagslys, solvarme?
    - Møblerede I på en bestemt måde i det gamle hus i forhold til lyd, lys eller luft/træk?

Luftkvalitet (luftfugtighed):

29. Hvad synes du generelt om luftkvaliteten i boligen? Tør, fugtig, frisk, tung, dårlig lugt, tæt?

- Gør du sommetider noget for at forbedre den? Hvad?
- Luftes der ud? Hvordan, hvornår og hvor ofte?

30. Hvordan oplever du/I at have et mekanisk ventilations anlæg? Har du/I tillid til at det kører som det skal?
    - Hvordan opleves det at ventilationsanlægget leverer den friske luft? Og du ikke behøver at åbne vinduerne? Er det rart?
    - Hvordan opleves det at du ikke kan variere temperaturen i hvert rum? Hvordan opleves temperaturen i soveværelset?
    - Hvor tit ændrer du/I på anlæggets indstillinger og hvad er årsagerne?
31. Oplever du/I nogen gange kondens på yderside eller inderside af vinduerne? Acceptabelt eller ej?

Lyd

32. Kan du/I beskrive hvordan du/I oplever lydforholdene i boligen? Evt. i forhold til tidligere bolig. Ok, almindelig, rungede, ekko, død?
    - Har du/I oplevelser med internstøj inde i boligen, f.eks. mellem værelserne eller ventilationsanlægget?
    - Hvordan oplever du/I ”nabo”støj eller mangel på sammen? At høre at der kommer nogen hjem – bil eller trin eller forårets fuglefløjt. Vænnet dig til det?

Dagslys

33. Vi har været inde på dagslyset, men er det steder hvor I specielt synes dagslyset er godt?
    - Hvordan oplever I farven på dagslyset? Er der filtre på glasset, som ændrer farven?

Generelt:

34. Hvordan oplever du boligens indeklima i forhold til den tidligere bolig?
35. Er du mere bevidst om indeklimaet i din bolig i dag?

Aktivitetsmønstre

Jeg vil nu bevæge mig over til at høre lidt om hvordan en gennemsnitlig hverdag ser ud for jer. Formålet er at få et billede af jeres hverdagsliv i et komfort hus.

36. Er der noget i jeres dagligdag I har lagt mærke til, som har ændret sig, siden I flyttede in i Komfort huset?
    - Pga. arkitekturen, passivhus konceptet etc?

37. Hvad gør du på en helt almindelig dag fra du står op til du går i seng? Husk begrundelser!
    - Hvad fortager du dig? Lad os starte om morgenen…
    - Hvad er det første du gør, når du står op om morgenen?

- Hvad er det sidste 3-4 ting du gør inden du tager af sted om morgenen/ på arbejde?
- Ændrer trin på ventilationsanlægget?
- Hvad er det første du gør når du kommer hjem om eftermiddagen? Og derefter?
- Ændrer trin på ventilationsanlægget?
- Hvilke aktiviteter foregår der (madlavning, tøjvask, gæster, besøger venner, hobbyarbejde, sport, læser, tv/dvd/pc, ude i byen, på ustillinger, i naturen osv.)?
- Hvordan omgår du venner? Inviterer, uanmeldt, arbejdsrelateret, ude i byen, venner fra forening/klub etc.
- Hvilke aktiviteter laves med gæsterne/vennerne og hvor?
- Hvor opholder I jer mest i huset? Hvorfor? Tiltrækkes I af solvarmen?
- Hvad sker der om aftenen? Hvem gør hvad, sammen/individuelt? Hvor og hvorfor?
- Gør i noget bestemt hver dag inden i går i seng om aftenen?
- Ændrer trin på ventilationsanlægget?
- Hvordan er temperaturen i soveværelset? Som resten af huset eller ønsker du den koldere? Hvis ok med samme temperatur, var det også sådan tidligere og hvorfor er det ok?

Krav til boliger i fremtiden

Mit sidste spørgsmål lyder:

38. Har I nogen krav om indeklimakomfort eller energiforbrug til en evt. fremtidig bolig? Det samme som denne bolig eller som den tidligere bolig? Hvorfor?