

## **A Model for Enquiry of Sustainable Homes**

*of Model Home 2020*

Olesen, Gitte Gylling Hammershøj

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The background of the cover is a photograph of a modern building's interior. It features light-colored wooden walls and ceiling, with dark, angular shadows cast by the architectural elements, creating a dramatic, geometric pattern.

PhD Thesis

# A Model for Enquiry of Sustainable Homes *of Model Home 2020*

by  
Gitte Gylling Hammershøj Olesen  
January 2014

Aalborg University  
Department of Architecture, Design & Media Technology  
Research Group for Sustainable Architecture - SARC



Aalborg University

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PhD dissertation

# A Model for Enquiry of Sustainable Homes *of Model Home 2020*

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(Spring 2014)

By

Gitte Gylling Hammershøj Olesen

January 2014

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A Model for Enquiry of Sustainable Homes  
*of Model Home 2020*

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*Encountering Sustainable Functionalism: Occupant Perspectives on Automated Life-form*  
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Article #3: Gitte Gylling Olesen and Mary-Ann Knudstrup (2013) *Enquiring Perceived Quality in Sustainable Architecture: A More Tangible Approach*  
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Paper #4: Gitte Gylling H. Olesen & Mary-Ann Knudstrup (2013) *Aesthetic Quality in Sustainable Houses: Sensory Experiences of Atmospheres*. Presented at International conference and annual meeting of the Nordic Association for Architectural Research, Conference: *Aesthetics, the uneasy dimension in architecture*, Faculty of Architecture and Fine Art, Trondheim, Norway. Accepted for publication in collaboration with Akademika.

PAPER #5: Gitte Gylling Olesen, Mary-Ann Knudstrup, Per K. Heiselberg, Ellen K. Hansen (2011b) *Measuring Sustainable Homes – A Mixed Methods Approach* in Plowright, P. (ed.) and Bryce, G.. (ed.) (2011) The ARCC 2011 Spring Research Conference, Conference proceedings: *Considering Research: Reflecting upon current themes in architectural research*, Architectural Research Centers Consortium, Lawrence Technological University, Detroit, Michigan, pp. 435-447. (Published)

PAPER #6: Gitte Gylling Olesen, Mary-Ann Knudstrup, Per K. Heiselberg, Ellen K. Hansen (2011a) *Holistic Evaluation of Sustainable Buildings through a Symbiosis of Quantitative and Qualitative Assessment Methods* in Bodart, M. (ed.) and Evrard, A. (ed.) (2011) 27th International Conference on Passive and Low Energy Architecture PLEA 2011, Conference proceedings: *Architecture and Sustainable Development*, vol.2, UCL Press Universitaires De Louvain, pp. 11-16. (Published)

*This thesis has been submitted for assessment in partial fulfilment of the PhD degree. The thesis is based on the submitted or published scientific papers which are listed above. Parts of the papers are used directly or indirectly in the extended summary of the thesis. As part of the assessment, co-author statements have been made available to the assessment committee and are also available at the Faculty. The thesis is not in its present form acceptable for open publication but only in limited and closed circulation as copyright may not be ensured.*

## Preface

---

This thesis is a result of an Industrial PhD work carried out in collaboration between Department of Architecture, Design & Media Technology and Department of Civil Engineering, Aalborg University, Investment and Holding Company VKR Holding A/S and roof window producer and Green Growth Thought Leader VELUX A/S. The work was carried out from winter 2009 till winter 2014.

The aim of the work is to develop a *Model for Enquiry of Sustainable Homes* through exploration of built, in-use, sustainable homes; three Model Home 2020 houses and families living in them. Aiming at complying with the complexity of the world of sustainable architecture, the model employs methods of enquiry through four different perspectives; namely in-situ research, blog research, questionnaire survey and technical measurements. Thereby several aspects of the built environment come together in creating a more complete understanding of what sustainability actually entails.

The starting point for developing such a model is a belief that in order to develop successful sustainable solution for the future built environment, focus must turn back to very fundamental aspects of being in the world and exist in coherence with the surroundings. Because, that is in the basic understanding what sustainability is all about; sustainable encounters with surrounding environments; whether natural or constructed.

To begin comprehending this relation, the surroundings must be understood from ourselves and what we come from. Peter Zumthor writes:

*“We all experienced architecture before we have even heard the word. [...] The roots of our architectural understanding lie in our architectural experience: our room, our house, our street, our village, our town, our landscape, - we experience them all early on, unconsciously, and we subsequently compare them with the countryside, towns, and houses that we experience later on. The roots of our understanding of architecture lie in our childhood, in our youth; they lie in our biography.”*

*Peter Zumthor (Zumthor, 2006, p.65)*

This work contains an inherent agenda of measuring. It attempts to measure all from technical ability over occupants' experience to elements of perceived quality in sustainable homes. At the same time, there is an awareness that this may not be entirely possible, seen in the nature of the unmeasurable character of architecture. Hawkes describes this relation beautifully:

*'I only wish that the first really worthwhile discovery of science would be that it recognized that the unmeasurable is what they're really fighting to understand, and that the measurable is only the servant of the unmeasurable; that everything that man makes must be fundamentally unmeasurable.'*

Dean Hawkes (Hawkes, 2008, p. vi)

I would like to move discussion of sustainability away from the inherent quantitative/qualitative divide between architecture and engineering approaches where the respective professionals consider themselves belonging to different disciplines with separate agendas. Rather, I would like to take holistic view point on sustainability within architecture and thematically explore the abilities and possibilities in the built environment of the future. Disregard whether knowledge stems from engineering, architectural, anthropological or social science but choose methods and knowledge fields best applicable and usable for exploring and understanding specific challenges and areas of interest.

From this basis, this thesis will attempt illustrate a sincere wish to direct focus at the complex nature of the built sustainable environment, its numerous challenges and its immense potential.

Due to copyright restrictions this PhD dissertation has only been published in a limited number of issues and cannot be reprinted without authorization the author, co-authors and from publishers of the scientific articles. Thus, conference papers are available through public libraries and technical reports through VELUX A/S.

Aarhus, January 2014

Gitte Gylling Hammershøj Olesen

## Acknowledgements

---

*During the past years quite a few people have crossed my ways. Each, they have somehow contributed to the outcome of this work. These people have taught me about life, academia, industry and reality. They have made me realize that a sustainable life and future is more but merely a matter of energy. It is a basic understanding of how encounters with the world leave different types of traces of perceptual or technical character. I would like to take this opportunity to thank everyone with whom I have crossed paths to get here!*

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First and foremost I would like to thank main supervisor Professor Mary-Ann Knudstrup, Department of Architecture, Design & Media Technology, for her enormous engagement, persistency, guidance and support; and supervisor Professor Per Heiselberg, Department of Civil Engineering, for guidance, precise critique and support.

Participation in Strategic Centre of Zero Energy Buildings activities has lead to many new acquaintances; thank you all for knowledge exchange and enriching experiences.

Thank you to Department of Architecture, Design & Media Technology; especially to administrative staff, the PhD Lab ADPL and PhD fellows.

### **VKR Holding A/S**

I would like to thank VKR Holding for initiating the idea behind the project at the time. The idea of an Industrial PhD position was unknown territory and due to a courageous and farsighted staff the project became a reality.

A special thanks to my first, main company supervisor Ellen Kathrine Hansen. Thank you for opening your world of knowledge to me, inviting me in and introducing me to daylight and interesting people. You have shed light my professional being and taught me an unfiltered curiosity and the holistic importance of light and sustainability.

Thank you to the entire house of VKR Holding for welcoming me with open arms and giving me a truly wonderful workplace filled with hospitality, laughs and friendship. An enormous thank you to Issues Management and Communication including Mia Mercedes Kranker, Ellen Kathrine Hansen, Kristina Vang Jacobsen, Kurt Emil Eriksen, Normann L. Sloth, Nathali Selmeczi Leth, Anette Haaning, Michael Boisen, Pia Hansen and Kim Martinussen. A heartfelt thank you to Company History for outstanding laughs!

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I would like to thank VELUX for an ambitious and professional approach to developing solutions for the future sustainable environment. It has been a pleasure to be part of a company group with such an admirable agenda, unique history and products. Thank you for amazing VELUX Daylight Symposium and Academic Forums; a special thank you for professional critique to Steve Fotios and the compassionate PhD fellows.

#### **Active House & Model Home 2020**

Without the remarkable Active House vision and realization of Model Home 2020 project, this enquiry would not have been possible. Numerous people were involved in the demanding processes of developing, designing, constructing, maintaining, monitoring, researching and commissioning. I would especially like to thank:

VELUX. LichtAktiv Haus: Oldendorf family, Jan Ostermann, Manfred Hegger. Sunlighthouse: Dorfsetter family, Heinz Hackl, Juri Troy, Peter Holzer and Renate Hammer. Maison Air et Lumière: Pastour Family and Catherine Julliard, CarbonLightHomes: Glazebrooke family, Carse family and Paul Hicks.

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SONNENKRAFT. Jeppe Falk. Haus der Zukunft: Markus Staudigl and Stephan Fabi. SolarAktiv Haus: Georg W. Reinberg and Thomas Kraig.

WindowMaster. Steen Hagberg, Sten Hagelskjær, Ulrich Thomsen and Jesper Darum.

#### **Family and friends**

I would like to thank my family and friends for their patience, practical assistance and moral support. My mother, father, sisters and brother for immense help, strength, love and support. My daughter Karen for her spontaneous smiles, laughter and love; and for making it all worth it. My in-laws for their enormous practical and emotional support.

Most of all, my deepest gratitude to my best friend, my harshest critiques, my conscience, my honest opinion, my love, my husband Andreas.

## Abstract in English

---

This Industrial PhD project is formed in collaboration between holding and investment company *VKR Holding A/S*, International roof window producer and thought leader *VELUX A/S*, the *Danish Board of Research and Innovation* and *Department of Architecture, Design and Media Technology, Aalborg University*. The project revolves around the *Active House vision* and three demonstration houses in-use developed within the frame of *VELUX based Model Home 2020* project.

The objective of this thesis is to develop a Model for Enquiry of Sustainable Homes. The purpose is to establish multi-perspective enquiry of inhabited sustainable homes based on intention to create a more complete illustration of sustainable life but the technical measurable ones development of sustainable architecture is mainly driven by today.

Thus, the main research question is:

- I. *How can a model for enquiry of sustainable homes based on a mixed methods approach include occupant perspectives, perceptual quality and technical ability; so the approaches supplement each other and establish a holistic illustration of the sustainability unfolded?*

To explore how such a model can be compiled the research enquire how sustainable homes in-use can be evaluated from different fields of knowledge and methods. As a first step to explore this, aspects of occupant perspectives are enquired:

- II. *How are everyday encounters with sustainable functionalism perceived by occupants, and what aspects does this bring to an automated, sustainable life-form which is probably a circumstance of the future?*

Based on the research question the article '*Encountering Sustainable Functionalism: Feedback as a Method to Raise Awareness on Energy Use and Indoor Environment in Automated Homes*' (Olesen et al., 2013) explores how a multiple method approach including questionnaire survey and blog posts can provide information on experiences of life in sustainable homes. The article concludes that providing occupants' information on energy and comfort support and motivate their ability to pursue sustainable life-form.

Secondly, aspects of perceived quality are enquired:

- III. *Aspects of perceived quality are central to create value for human beings in the built environment of the future, but how can perceived quality in sustainable architecture be registered, analysed, weighed up and conveyed without losing their qualitative nature?*

From this question the article '*Enquiring Perceived Quality in Sustainable Architecture: A More Tangible Approach*' (Olesen & Knudstrup, 2013b) forms a scheme for collection, treatment and dissemination. Conclusions are that focus on daylight, fresh air, every-day functionalism and natural resources add to the perceived quality of the houses.

Acquired knowledge is compiled in a holistic model of enquiry which is applied through empirical testing of indoor environment in three Model Home 2020 homes:

IV. *How can indoor environment in sustainable homes be enquired through respectively occupant perspectives, perceptual quality and technical ability; so the approaches supplement each other and establish a holistic illustration of the sustainability unfolded?*

The article '*Exploring a Model for Enquiry of Sustainable Homes through Indoor Environmental Aspects*' (Olesen et al. 2014) suggests and empirically enquire a holistic model that compiles data from four knowledge fields respectively, architectural field studies, occupant blogs, occupant questionnaires and technical measurements on perceived indoor environment. Conclusions are that the houses generally have high quality indoor environments and that the variety of methods are appropriate for capturing dissimilar aspects of sustainable life-form and thereby supplement each other in creating a more holistic illustration sustainable homes in-use.

Future sustainable buildings are not merely optimized mechanical constructions with intelligent adjustment systems but houses that imply and require quality in their environments to support and embrace life displayed in and around them. Therefore, it is becoming increasingly central to develop more holistic approach to enquiry and thereby the understanding of sustainable environments is viewed in balance between perceptual qualities as well as technical abilities. Results of this thesis are thus:

- i. A model for enquiry of sustainable homes that include occupant perspectives, perceptual quality and technical ability.
- ii. Occupant perspectives of perceived everyday encounters with automated homes through a combination of questionnaire and blog enquiry.
- iii. Enclosure of perceived quality in enquiry of sustainable architecture and a more tangible approach to collect, treat and explore aspects of perceptual nature.
- iv. Focus on aspects of variability in enquiry of sustainable architecture.

## Resumé på dansk

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Dette ErhvervsPhD-projekt er skabt i et samarbejde mellem holding- og investeringsselskab VKR Holding A/S, International ovenlysvinduesproducent og Thought Leader VELUX A / S, Forsknings- og Innovationsstyrelsen i Danmark og Institut for Arkitektur, Design og Mediateknologi, Aalborg Universitet. Projektet kredser om Active House visionen og tre demonstration huse i brug, der er udviklet inden for rammerne af det VELUX baserede Model Home 2020-projekt.

Formålet med denne afhandling er at udvikle en model til undersøgelse af bæredygtige boliger. Formålet er at etablere multi-perspektive undersøgelse af beboede bæredygtige boliger baseret på intentioner om at fange flere aspekter af bæredygtig livsform, end blot de teknisk målbare som udvikling af bæredygtig arkitektur er primært drevet af i dag.

Det primære forskningsspørgsmål er:

- I. *Hvordan kan en model til undersøgelse af bæredygtige boliger baseret på en mixed methods tilgang omfatte såvel beboer perspektiver, oplevet kvalitet og teknisk formåen, således at tilgangene supplerer hinanden i at etablere en holistisk illustration af den bæredygtighed der udfoldes?*

For at undersøge hvorledes en sådan model kan sammensættes, undersøger dette forskningsprojekt hvordan bæredygtige boliger i brug kan vurderes ud fra forskellige vidensområder og metoder. Et første skridt er undersøgelser af beboer perspektiver:

- II. *Hvordan opleves hverdagens møder med bæredygtig funktionalisme af beboerne og hvilke aspekter bibringer dette til en automatiseret, bæredygtig livsform, som sandsynligvis er en omstændighed for fremtidens levemåde?*

Baseret på forskning spørgsmålet undersøger artiklen 'Møder med Bæredygtig Funktionalisme: Feedback som en Metode til at Øge Bevidstheden om Energiforbrug og Indeklima i Automatiserede Hjem' (Olesen et al. 2013) hvordan en brug af flere metoder, herunder spørgeskemaundersøgelse og blogindlæg, kan give information om oplevelser af livet i bæredygtige boliger. Artiklen konkluderer, at feedback giver beboerne oplysninger om deres energi og komfort hvilket støtter og motiverer deres evne til en bæredygtig livsform.

Dernæst undersøges aspekter af oplevet kvalitet i bæredygtige hjem:

- III. *Aspekter af oplevet kvalitet er centrale for at skabe værdi for mennesker i fremtidens byggede miljø, men hvordan kan opfattede kvalitet i bæredygtig arkitektur registreres, analyseres, vejes op og transporteres uden at miste deres kvalitative natur?*

Baseret på dette spørgsmål danner artiklen: '*Undersøgelser af Oplevet Kvalitet i Bæredygtig Arkitektur: En Mere Håndgribelig Tilgang*' (Olesen & Knudstrup, 2013b) en ramme (skema) for indsamling, behandling og formidling. Konklusionerne er, at fokus på dagslys, frisk luft, hverdagsfunktionalisme og naturlige ressourcer føjer til den oplevede kvalitet.

Den indsamlede viden samles i en model til undersøgelse, der testes gennem anvendelse til empiriske undersøgelser af indeklimaet i tre Model Home 2020 boliger:

IV. *Hvordan kan indeklimaet i bæredygtige boliger undersøges gennem henholdsvis beboer perspektiver, oplevet kvalitet og teknisk formåen, således tilgangene supplerer hinanden i etableringen af en holistisk illustration af bæredygtighed udfoldes?*

Artiklen '*Udforskning af en Model til Undersøgelser af Bæredygtige Hjem gennem Indeklima Aspekter*' (Olesen et al., 2014) foreslår samt laver empiriske undersøgelser af en holistisk model, der samler data fra fire vidensfelter, henholdsvis arkitektoniske feltstudier, beboer blogs, beboer spørgeskemaer og tekniske målinger af det oplevede indeklima. Konklusionerne er, at husene generelt indeklima af høj kvalitet og at forskellige metoder er velegnede til at opfange forskellige aspekter af denne bæredygtig livsform og derved supplerer metoderne hinanden i at skabe en mere holistisk illustration bæredygtige boliger i brug.

Fremtidens bæredygtige bygninger er ikke blot optimerede mekaniske konstruktioner med intelligente justeringssystemer, men huse, der indebærer og kræver kvalitet i de rum de skaber til at støtte og omfavne livet der leves i og omkring dem. Derfor bliver det stadig mere centralt at udvikle en mere holistisk tilgang til undersøgelse og dermed forståelse hvor bæredygtighed ses som balancen mellem oplevelsesmæssige kvaliteter samt teknisk formåen. Resultaterne af denne afhandling er således:

- i. En model til undersøgelse af bæredygtige boliger, der omfatter beboer perspektiver, oplevet kvalitet og teknisk formåen.
- ii. Beboerperspektiver af opfattelsen af hverdagsmøder med automatiserede hjem gennem en kombination af spørgeskema og blog undersøgelse.
- iii. Introduktion af oplevet kvalitet i undersøgelse af bæredygtig arkitektur gennem en mere håndgribelig tilgang til at indsamle, behandle og formidle aspekter af oplevelsesmæssig karakter.
- iv. Fokus på aspekter af variabilitet i undersøgelse af bæredygtig arkitektur.



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*'I would like to move discussion of sustainability away from the inherent quantitative/qualitative divide between architecture and engineering approaches where the respective professionals consider themselves belonging to different disciplines with separate agendas. Rather, I would like to take a holistic view point on sustainability within architecture and thematically explore the abilities and possibilities in the built environment of the future. Disregard whether knowledge stems from engineering, architectural, anthropological or social science but choose methods and knowledge fields best applicable and usable for exploring and understanding specific challenges and areas of interest.'*

Gitte Gylling Hammershøj Olesen





A Model for Enquiry  
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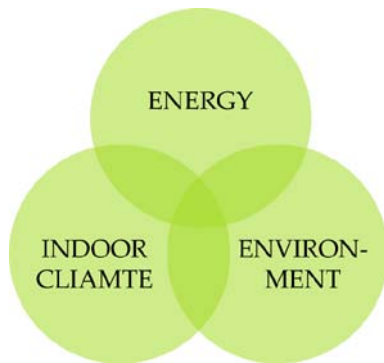






# PART I | Introduction

## 1.0 Background and motivation



### ACTIVE HOUSE VISION

#### ENERGY

***Contributes positively to the energy balance of the building.***

An Active House is energy efficient and all energy needed is supplied by renewable energy sources integrated in the building or room the nearby collective energy system and electricity grid.

#### INDOOR CLIMATE

***Creates a healthier and more comfortable life.***

An Active House creates healthier and more comfortable indoor conditions for the occupants and the building ensures generous supply of daylight and fresh air. Materials used have positive impact on comfort and indoor climate.

#### ENVIRONMENT

***Has a positive impact on the environment.***

An Active House interacts positively with the environment by means of an optimised relationship with the local context, focused use of resources, and on its overall environmental impact throughout its life cycle.

Energy consumption of buildings account for more than one third of the total consumption of energy in the Western World, and energy expenses of each household are increasing. The global climate agenda in particular focuses on energy consumption in and of buildings. (Aschehoug & Andresen, 2008; Andresen et al., 2010) Reduction of energy consumption, switch-over to new forms of energy, renewable energy implementation, optimization of resource utilization and protection of basic natural resources are becoming increasingly urgent issues for the health and safety of the international community. (Brundtland, 1990) Sunlight has the highest theoretical potential of natural resources available: *"The theoretical potential of solar power is the integral of this average flux over the earth's surface area ( $4\pi r^2$ ) (...) This theoretical potential represents more energy striking the earth's surface in one and a half hours (480 EJ) than worldwide energy consumption in the year 2001 from all sources combined (430 EJ). This theoretical potential could be used to generate 15 TW of C-neutral power from 10%-efficient solar-conversion systems covering only 0.17% of the earth's surface area = 858,792 km<sup>2</sup>."* (Tsao, Lewis and Crabtree, 2006)

#### Active house vision – a holistic approach

Potentials in utilising free natural energy resources are immense. The level of technical ability researched today provides an array of ways to solve this sunlight potential to power sustainable buildings (Voss & Musall, 2012). How can all this free energy be used in creating future sustainable environments?

The Active House vision is one suggestion. Active House vision (Sloth, 2010) defines highly ambitious long term goals for the future building stock. The purpose is to unite interested parties based on a balanced and holistic approach to building design and performance and to facilitate cooperation on e.g. building projects, product development, research initiatives and performance targets that can move development towards fulfilling the vision. Active House proposes a target framework for how to design and renovate such buildings that contribute positively to human health and well-being by focusing on the indoor and outdoor environment and the use of renewable energy. Thereby the vision aims at holistic solutions that take multiple aspects into account.

Creating buildings that 'Contributes positively to the energy balance of the building', 'Creates a healthier and more comfortable life' and 'Has a positive impact on the environment' is an excellent vision and sounds very appealing but is it possible?

#### III. 1.0.1. Active House Vision

*Main points of the Active House Vision and diagram illustrating overlapping between the themes. (Sloth, 2010)*

### **Model Home 2020 demonstration buildings**

To explore potentials in the Active House vision and be able to measure it against state of the art products, International roof window company VELUX A/S in 2008 launched the Model Home 2020 project. The project is part of a wider company strategy of developing and researching products and solutions for future energy and livability challenges. The intent with the *Model Home 2020* strategy is to combine excellent indoor environment with high quality homes mainly driven by renewable energy sources as contextually optimized design solutions. The Model Home 2020 is materialised in six demonstration buildings, houses are designed, built and constructed as state-of-the-art homes with the newest technological developments and high quality materials as net zero energy buildings (Marszal, 2012; Marszal et al., 2012). The background for this research is to enquire how three of these Model Home 2020 buildings function when they are inhabited and thereby in-use. These houses provide opportunity to gain knowledge from in-use situations. (VELUX, 2010)

What happens after design and construction when the houses and products are in-use? When ideas and visions of sustainable life-form encounter challenges of everyday life and sustainable functionalism? What can we learn about the potentials of architecture to create better, healthier and more comfortable built environments for future life-forms? The in-use aspect provides introduction a dynamic human factor which is often not included in development of sustainable architecture – maybe due to its complex and ever-changing character? (Hawkes, 2008)

### **Motivation**

The motivation for this research is an explicit interest in the interplay between human being, architecture and technology and an aim to provide the best possible built environment for the future. The curiosity in this research circles around occupant perspectives and perceived quality. It attempts to explore how aspects of perceptual nature can be implemented in enquiry of sustainable buildings with a purpose of creating valuable environments that will be durable and thereby sustainable in more than a technical sense. Buildings are not sustainable merely due to their ability to reduce energy consumption or produce a certain amount of kWh. Sustainability exist in the structures ability to give more than it takes ALSO in a perceptual sense and thereby contribute to improving quality of life to occupants. In order to create suitable homes that motivate sustainable life-form occupant perspectives should be included!

*Previous spread (p. 1-2)*

#### **III. 1.0.0. Shadow play**

*The photo is a close up of the staircase space in Licht Aktiv Haus, Germany.*

*The direct sun plays with the grid structure of the shielding along the stairs and leave shadow patterns on the steps and in the tall space.*



## 1.2 State-of-the-Art:

### Enquiry of sustainable homes in-use

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*This project is engaged in enquiring sustainable homes in-use – what happens after buildings are designed, constructed and the occupants have settled in? This chapter provides insights in State-of-the-Art of how sustainable homes in-use are enquired.*

Building industry, product developers, architects and engineers commonly focus their attention on design and construction processes; but for the occupants, the users of the building, the life in the buildings and the creation of home starts only when construction ends. The real measure of sustainability of a building depends on its ability to meet its user's needs and desires. (UN, 1992) With increasing focus on sustainability and coherent development in legislation, focus on buildings performance has been increasing since the 1992 Rio Summit (UN) and the 1998 Kyoto Agreement (UN) set Global target goals for reduction of CO<sub>2</sub> emission and energy consumption. Measures to calculate and enquire effects of the built environment has lead to development of environmental assessment tools and models categorized as e.g. 'Building Performance Evaluation' (BPE), 'Building Evaluation Assessment' (BEA), 'Sustainability Assessment Model' (SAM) and 'Life Cycle Assessment' (LCA). Examples of tools for in-use situations are BREEAM in Use and Code for Sustainable Homes. (Edwards, 2010) (Preiser & Vischer, 2005)

#### Post-occupancy Evaluation

A branch of BPE is Post-Occupancy Evaluation (POE). It can be defined as '*the act of evaluating buildings in a systematic and rigorous manner after they have been built and occupied for some time.*' (Preiser, 2002) POE entail systematic evaluation of occupant perspectives about the buildings and it explores and assesses how well the buildings meet user needs and wishes. Current views on POE suggests it cover technical performance, economy, user satisfaction and impact of the building on living conditions. It can identify opportunity to improve the design, performance or functionality through feedback knowledge. POE's are conducted worldwide on existing as well as new-built houses (e.g. Hygge & Löfberg, 1999; Newsham, 2005; Birt & Newsham, 2009)

#### Empirical enquiries of sustainable demonstration buildings

Across the World the number of sustainable demonstration net zero energy buildings in-use is increasing and a research group within in IEA's *Towards Net Zero Energy Solar Buildings* has identified and analysed almost 300 net zero

energy and energy positive buildings (Voss & Musall, 2012). The first of these buildings were constructed in the beginning of the 1990ies and were intended as pioneering examples and scientific experiments. The first buildings focused on covering their heating needs. Later, through the 2000s ideas of balancing energy consumption and production were brought into play. (Voss & Musall, 2012; Aschehoug & Andresen, 2008; VELUX, 2010) Realisation of sustainable Net zero energy buildings provides for possibility to enquire and explore POE's of different character in different climatic settings, cultures, traditions, and relations. Collaboration between building industry, specialist professionals and academics are becoming increasingly common (e.g. ZEB, 2013) requiring new ways of approaching enquiry and high demands for communicability. The following will explore examples of how buildings are enquired.

#### **Enquiry of residential sustainable demonstration buildings in-use**

'Danish project 'Comfort houses' (Larsen & Brunsgaard, 2012) and 'Home for Life' (Hansen et al. 2013; Hansen & Olesen, 2011) are examples of demonstration buildings in use with test families living in them for longer periods. Research projects imply application of numerous methods provide knowledge on several levels. They illustrate how technical measurement can be supplied by methods from social sciences such as questionnaires or interviews. Thereby, research problems are explored from several perspectives where knowledge obtained through technical means can be elaborated through for instance user statements, adding layers of qualitative knowledge. The approach has proven valuable to provide an expanded understanding of the actual in-use experiences and to explain technical conditions.

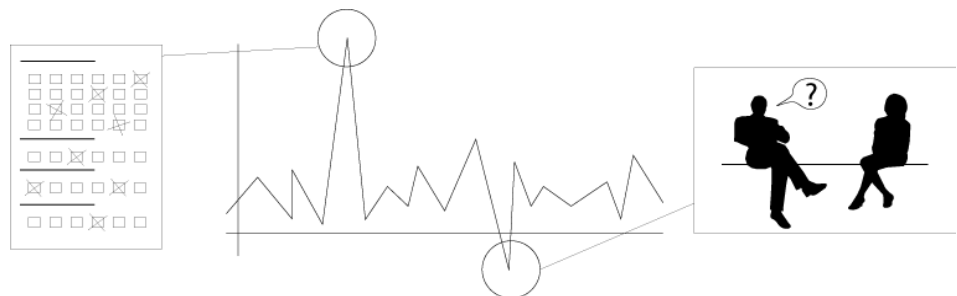
In United Kingdom 'BASF House' and 'The Uptown Homes project' (Poblete, 2013) are enquired by means of what is named first-person research coupled with technical sensors (48 sensors installed to measure). Poblete writes: "Hands on' experience makes it possible to identify, select and verify real and direct problems that expect the expected performance of sustainable homes. Another English research project suggests using BIM (Building Information Modelling) and sensing devices tested on 'Salford Energy House' (Ozturk et al., 2011) focusing on optimising evaluation models based on sensory measured data. In Scotland 'Orkney Houses' and 'Glasgow flats' are enquired through onsite technical measurements paired with questionnaire aiming at developing a three level physical and social survey methodology (Sheridan, 2009). Drexler and El Khouli (2012) makes enquiries of 'Holistic Housing' by assessing 15 house across the world using 'The Housing Quality Barometer' (ibid) where they use a scale of five quality rating levels for assessing 79 criteria. The scale includes levels: I) Exemplary/best practice; II) Innovative/target value; III) Above

average/good; IV) Standard/reference value; and V) Below average/critical value.’ (Olesen et al. 2014) (See. III. 1.2.1.)

The project Home for Life, Denmark, is the first single-family house built on basis of the Active House vision (Sloth, 2010). An interdisciplinary team follow the house through two test periods of one year, where two respective test families live there. The research project is a cross disciplinary collaboration (Hansen, 2010) and enquiry focus is on occupants experience with living in an intelligent and automated house, energy consumption, indoor environment and commissioning. The project, among other discoveries, finds that the house acts differently than calculation indicated mainly due to inadequate tightness, user behaviour and overruling automation (Hansen et al., 2013; Hansen & Olesen, 2011). There are indications of challenges in transitional periods between summer and winter where the house shifts from mechanical to natural ventilation. (Entwistle, 2010; Hansen 2010; Österhaus 2010; Foldbjerg et al 2010) Daylight engineer Österhaus (2010) enquire the house through an expert perspective on daylighting where spot measurements inside the house are carried out simultaneously to more narrative registrations of the conditions. These data are merged into an illustrated explanatory and technically supported report, documenting the high quality of daylight in the environment of Home for Life. Anthropologist Entwistle (2010) makes a range of studies on the occupants in the house. Participant observation, Cultural Probes and Semi-structured Interviews are some of the methods she uses to explore their life. Based on Home for Life, Hansen and Olesen (2011) study the window as a poetic device and technical tool to identify holistic potential of the window as design element. The study explores five parameters analysed by variable orientation, by applying different methods in a compilation of quantitative and qualitative approaches. The study is concluded in an assessment table with illustration about to which degree the respective parameters holds positive or negative potential. A similar approach is taken by Hansen, Olesen and Mullins (2013) where connection between technology and user needs are illuminated through a ray of methods from quantitative and qualitative disciplines of knowledge.

### III. 1.2.1. Enquiry approaches

Several methods are used for enquiry of sustainable homes. The diagram illustrates that technical measured data results can vary and catch peaks. These peaks are then subject to further enquiry through more qualitative methods such as questionnaire or interview.



### Approaches based on social and humanistic knowledge fields

Qualitative approaches to enquiring sustainability, especially indoor environmental aspects, in built environments, is a discipline in development where application of methods and approaches from other sciences, mainly social and human sciences, is increasing (e.g. Kvale, 2009; Boolsen, 2008; Bryman, 2008; Brinkmann & Tanggaard, 2010; Creswell, 2009). The built environment provides excellent possibility to apply and reflect on social problems and aspects. Anthropologist Bettina Hauge (2010) in her study *Fresh air at home: a sensory experience and social ritual* through qualitative interviews explore how people make use of fresh air to air out their homes by looking at three aspects: functional (practical causes), aesthetic (sensory) and social (caring for and impressions on others) (Hauge 2010a; Hauge 2010b). This approach results in qualitative findings in the form of statements on the theme of airing out (Hauge 2010a). In SBI's (Danish Building Research Institute) publication *Light in the School* (2004) a scheme for qualitative analysis of light conditions in schools has been concretized by structuring the analysis in diagram format where assessment of the selected parameters consist in written descriptions and observations accompanied by a list of questions to elaborate the themes in the scheme. The result of the analyses is a filled in scheme. The MCHA project is an example of an anthropological user-study of need, motivation and barriers concerning energy consumption in the home. The project established in collaboration between anthropologies, engineers, industrial partners and authorities with cross-disciplinary focus, however the research is mainly unfolded through qualitative methodology, including User Driven Innovation, Interviews, Cultural Probes, and Observations communicated through eleven themes. (Larsen, Entwistle & Søndergaard, 2009)

### Wide range in perspectives for enquiry

The brief overview above illustrate that several methods are applied in practice to enquiring aspects of sustainable environments from quantitative and qualitative as well as mixed methods approaches. These imply good intentions and insights that sustainability is not merely a technical issue, as was the main focus through years; and with the developing pace of sustainable solutions to creating homes, more mixed methods enquiry seems appropriate. With an increasing focus on integrated design and increasingly complex building solutions the course point in a similar development within enquiry. It would be desirable to integrate more different perspectives to enquiry of different elements of sustainability. This work therefore proposes a model which includes several perspectives on dynamic in-use aspects of sustainable homes; through occupant perspectives, perceptual qualities based on in-situ registration and technical ability based on measurements.



#### III. 1.2.2. Anthropological enquiries

*Anthropological enquiries in occupant experiences and behavior – an example of how recording devices can be used to support data collection processes.*

*Photo by Normann Sloth*

## 1.3 Themes for research

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*Through studies on the previous pages a range of tendencies in enquiry of sustainable architecture are identified, including Holistic and balanced approaches, The human in centre, Perceived indoor environment, and Perceived quality in architecture. Below, these tendencies are listed and substantiated. These themes form the foundation for further enquiry through this work and will be elaborated and substantiated below.*

### 1.3.1 Holistic and balanced approaches

As tendencies of holistic approaches to sustainable architecture develops the incentive to also approaching enquiry of these in a holistic approach increases. A mixed methods approach is more commonly used to capture and illustrate the duality between quantitative and qualitative aspects. The more interweaved ideas about the house the less sense it makes to separate these with regards to enquiry.

#### **Mixed Methods Enquiry**

The mixed methods approach is gaining footing within building research where an inherent relation (e.g. Vitruvius) between quantitative technical aspects and qualitative sensuous aspects is reviving as development and realization of sustainable architecture projects appears (Entwistle, 2011, Larsen et al., 2012, Brunsgaard et al., 2012). Building research is concurrently expanding its scientific platform to embrace various fields such as healthcare, nutrition, experience economy, service design research etc. (e.g. AD:MT 2012) where tendencies to give increasing attention to human aspects is becoming visible. This shift has caused for social and human sciences to gain ground in building research, as Creswell formulates it:

*“(...) mixed methods is another step forward, utilizing the strengths of both qualitative and quantitative research. Also, the problems addressed by social and health science researchers are complex, and the use of either quantitative or qualitative approaches by themselves is inadequate to address this complexity. The interdisciplinary nature of research, as well, contributes to the formation of research teams with individuals with diverse methodological interests and approaches. Finally, there is more insight to be gained from the combination of both qualitative and quantitative research than either form by itself. Their combined use provides and expanded understanding of research problems” (Creswell, 2009, p. 203)*

### **Examples of Mixed Methods research in sustainable architecture**

As Mixed Methods research is gaining footing in sustainable houses in-use it is relevant to explore how this is approached to uncover methods and strategies. Below are reflected on the examples presented though State-of-the-Art (pp. 5-8).

Brunsgaard et al (2012) carries out a strategy of enquiring through both technical measurements and semi-structured Interviews (Kvale, 2009) and thereby provides an example of a mixed methods explanatory sequential design where quantitative data collection and analysis is followed up by qualitative data collection and analysis and then interpretation (Creswell & Plano-Clark, 2011). The EnergyFlexHouse project is enquired through extensive measurement on the continuously adjusted technical equipment while user experiences are captured through questionnaires and interviews (Stjernquist, 2010). This follows an explanatory sequential design (Creswell & Plano-Clark, 2011). The Home for Life project showcases an example of convergent parallel mixed methods design where respectively quantitative and qualitative data collection and analysis are carried out separately and then following are compared. (Creswell & Plano-Clark, 2011) Hansen, Olesen & Mullins (2013) work illustrates a convergent parallel methods design which is also the case for Poblete in her two case studies of UK demonstration houses (2013). (Creswell & Plano-Clark, 2011) Sheridan (2009) pursues an explanatory sequential design through her studies in developing new methodology for Scottish housing. Through their enquiry of fifteen houses Drexler and El Khouli (2012) world using 'The Housing Quality Barometer' (ibid) where they use a scale for rating assessing criteria; they pursue an explanatory concurrent design. (ibid)

Through the projects reflected a shift from technology to human as central in sustainable architecture becomes evident. More and more enquiries on occupants, and thereby methods from social sciences are applied; this point towards need for more holistic and balanced approach in enquiry.

### **Increasingly holistic tendencies**

Increasingly holistic tendencies in sustainable architecture call for more holistic and balanced approaches to enquiry when the buildings are built and in use. If assessment is continuously based on mainly technical means learning's and findings will reflect this and knowledge of more perceptual character will most likely languish. Perceptual aspects of the built environment are imperative to create spaces for people to unfold their lives in. Qualities related to home and surroundings are central in creating better and more fulfilled lives.

### 1.3.2 The human in centre

From the 1970ies and on technology is the main driver for development of sustainable buildings but during the later part of the 2000s the focal point is shifting to the users of technology, the human being. Thereby re-introduction of a human factor places the human being in the centre of sustainable architecture as the key to solving sustainability.

#### User behaviour

User behaviour has high influence energy consumption as well as level of comfort in homes. Every decision the user makes influence the way the house will perform whether this regards reduction of energy consumption or establishing a comfortable indoor environment. (Brunsgaard, 2012; Jensen, 2009; Gram-Hanssen, 2011; Gram-Hanssen, Kofoed & Nærvig Petersen, 2004) Therefore, it is central to understand the user and to explore and develop knowledge on how occupants experience living in and with automated homes.

Considering the human being central in architecture is no new thing. Actually, the human has been central ever since architecture was merely a matter of creating shelter (Frampton, 1995). This has been forgotten several times through history and especially the Industrialisation lead focus from human to machine – a worldview fascinating development of Modern architecture (Frampton, 2007; Bluysen, 2009; Gideon, 2009; Bloomer & Moore, 1977). The Nordic regionalist architects meanwhile managed to keep focus on the human being and not be blinded by the ability of mechanical approaches (Pallasmaa & Sato, 2007; Weston, 2002, Schildt, 1997).

Alvar Aalto recognised the importance in considering human being the focal point of the building and thereby focused his architecture on the interaction between man and his environment:

*‘I mean the question of variability, the possibility of interaction between man and his environment and his objects, where the environment fulfils the psychological need for constant regeneration and change. It is obvious that his most intimate surroundings should be created with what I would almost like to call the automatic possibility of constant change.’* Alvar Aalto, 1935 (Schildt, 1997)

*“It is thus as important as ever today to take the human factor into account.  
(...) One might say that the human factor has always been a part of  
architecture. In a deeper sense, it has even been indispensable to making it  
possible for buildings to fully express the richness and positive values of life.”*

Alvar Aalto (1940, p. 281)

Opposite page (12)

**Ill. 1.3.1. Therme Vals, Vals,**  
Graubünden, Switzerland (1996) by  
Peter Zumthor.

**Ill. 1.3.2. Experimental Summer  
House, Muuratsalo, Finland (1953)**  
by Alvar Aalto.

**Ill. 1.3.3. Louisiana Museum of  
Modern Art, Humlebæk, Denmark  
(1958) by Wilhelm Wohlert &  
Jørgen Bo.**

### 1.3.3 Perceived quality in architecture

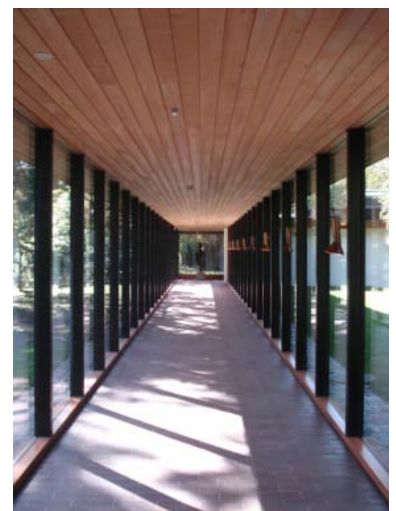
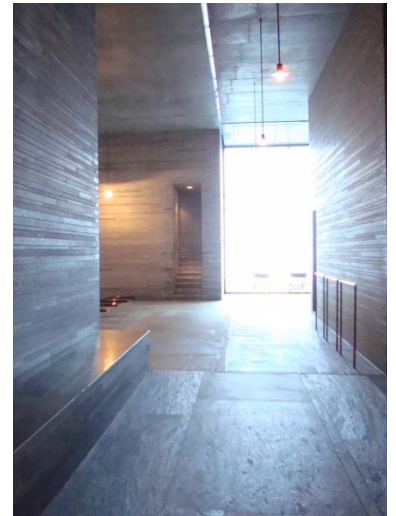
User experiences of life in sustainable built environments are increasingly frequently included in enquiry, and perception becoming more central. Aspects of perceived quality are paid increased attention in the design of sustainable architecture by means of creating quality to users. Nearness to natural and local resources such as landscape, microclimate, daylight availability, planting and possibilities of establishing views are considered in the designs. Among other things, this leads to closer relation with and interdependence of nature, its unpredictability and constant variability. (Olesen & Knudstrup, 2013a; 2013b)

#### Phenomenology & Perceived Quality

Architectural traditions have developed through centuries with strong inherent understanding for qualities based on e.g. cultural, scenic, spatial and social realms developed through an art of refining combination of materials, space, light, function and landscape. (e.g. Frampton, 2007; Wraber, 2009; Beijder, 2012, Lund, 2008) Architects are challenged and committed to visualize these qualities in the constructed environments they create, thus, architecture is much more but merely a visual thins (Pallasmaa & MacKeith, 2013). Theory behind perceived quality is based on a phenomenological worldview; a concept developed from the 18<sup>th</sup> century by Kant and Hegel and on by defined by Husserl and Heidegger (Heidegger, 1953) and later by Merleau-Ponty (1945; 1964); circling around examining meaning of life through lived experiences (see p. 26). Quality in the built environment is not merely a matter of aesthetic quality as has been the traditional interpretation, but rather a matter of atmosphere as denoted by Gernot Böhme (1993) and following by e.g. Rasmussen (1898), Zumthor (2006), Perez-Gomez, Pallasmaa & Holl (2006). Architecture proposes individual interpretation with the subject as a vital parameter and is created in the encounter between human being and building structure. This is supported and substantiated by theoreticians and architects (e.g. Rasmussen, 1989; Holl, 2006; Zumthor, 2006; Pallasmaa, 2005; Bachelard, 1994; Hawkes, 2008).

Buildings are constructed spaces filled with and surrounded by physical things. Some of these constructed spaces constitute homes and represent the most intimate frames people live their lives in. Accordingly Steven Holl:

*'Architecture holds the power to inspire and transform our day-to-day existence. The everyday act of pressing a door handle and opening into a light-washed room can become profound when experienced through sensitized consciousness. To see, to feel these physicalities is to become the subject of the senses' (Holl, 2006, p. 40).*







Putting on this sensitized consciousness is a central aim for this work to explore how sustainable build environments can potentially add to creating value in everyday life.

Means to explore and capture aspects of this sensitized consciousness can be based on a bodily and sensuous approach. Some of the greatest architects, both historically and contemporary, base their approach to creating buildings on this approach (e.g. Alvar Aalto, Jørn Utzon, Steven Holl, Peter Zumthor). They create from an understanding of the human being and the human body. Thereby, the spaces they create inherently relate to human bodies and minds and it is easy to understand and appreciate these buildings – because they make sense – on a fundamental sensuous level.

### Architects approaches

Hawkes (2008) reflects on this approach through the introduction to his book *'The Environmental Imagination – techniques and poetics of the architectural environment'* in which he tries to penetrate into the mindset of architects and show that *'the significant environmental proportions in architecture rest upon acts of imagination in which techniques are brought to bear in the service of poetic ends'* (Hawkes, 2008, p. vi). He pursues a method of direct experience, and distinguishes:

*'The essence of the environment I am trying to capture must be directly experienced; it cannot be completely discerned from images and verbal descriptions alone. For the purposes of this kind of research the only reliable instruments of observation are the human senses'*. (Hawkes, 2008, p. vi)



With Hawkes approach in mind studies of architects' approaches to understand their own buildings are enquired: *'Through enquiring writings by architects who approach architecture in a sensuously and bodily way, the question is reflected: How do architects approach understanding and conceptualizing perceived quality?'* (Olesen & Knudstrup, 2013b) The study enquires five works, respectively *Experiencing Architecture* by Steen Eiler-Rasussen (1989), *Open House* by Florentine Sack (2006), *The Eyes of the Skin* by Pallasmaa (2005) and Peter Zumthor's *Atmospheres* (2006a) and *Thinking Architecture* (2006b). Analysis of these works result in identification of a range of elements across the literatures which are representative to these architects view on perceived quality in architecture. The identified elements are compiled into categories: Perception, Relation, Composition, Surface, Light & Shadow, Variability and Utility. Elaborate description and analysis can be found in the article (Olesen & Knudstrup, (2013b).



### 1.3.4 Perceived indoor environment

Indoor environment is a central theme in the Model Home 2020 vision and project (VELUX, 2010). Therefore, naturally aspects of indoor environment has been paid great deals of attention though the design of these state-of-the-art sustainable single-family houses. The intent with the *Model Home 2020* strategy is to combine excellent indoor environment with high quality homes mainly driven by renewable energy sources as contextually optimized design solutions (VELUX, 2010). Thereby, the houses are designed, built and constructed with a focus on sustainability as more than merely a matter of energy reduction. Sustainability is also about creating good environments for people to live in.

These houses are built to explore possibilities in future technical as well as perceived sustainability. This coupling of measured and perceived resembles the complexity of real life to a wide extent compared to what approaches to sustainable building have done so far, as with for example the Passive Haus concept (e.g. Brunsgaard, 2011), where focus have been mainly on reduction of energy consumption, tightness of construction and air exchange rate.

By coupling more aspects, several approaches and perspectives are also necessary for indoor environment enquiry. Different knowledge fields have each their strengths to enquiry as these are founded in different world views and methodologies (Groat & Wang, 2013; Bryman, 2008; Creswell, 2009).

#### Theory on indoor environment

Hawkes' terminological reflections on environment are based on the definition of *New Oxford Dictionary of English* "the surroundings or conditions in which a person, animal or plant lives or operates" (Hawkes, 2008:xv) while in the *Medical-dictionary* indoor environment is defined as; "The physical, social and psychological environment within a human dwelling that can influence the health of a companion animal" (2013) The definitions thereby establish relation between the physical, social and psychological in which humans live and do not only include the technical but also embrace social and psychological aspects. This integral approach is partly why indoor environment is of immense importance to human well-being physically, emotionally, and sensuously (Andersen, 2012; Hau, 2011; Bluysen, 2009; Steemers and Steane, 2012; Pallasmaa, 2012a; Hawkes, McDonald and Steemers, 2002) and should be of primary concern of architects and engineers when designing and constructing buildings (Bluysen 2009; Hawkes 1996, p. 11). People in the Western World spend up to 90 percent of their time indoors (Jenkins et al., 1990 in Bluysen, 2009, p. 95; Gillet 2013, p-14; Andersen, 2012; Hau, 2011) and hereof increasingly more time is spend in their homes (Bluysen, 2009, p. 95) why this is an apparent place to aim at

Opposite page (13)

**III. 1.3.1. Notre Dame du Haut,**  
Ronchamp, France (1954) by Le  
Corbusier.

**III. 1.3.2. Saint Benedict Chapel,**  
Sumvigt, Graubünden, Switzerland  
(1988) by Peter Zumthor.

**III. 1.3.3. Church of Light,** Ibaraki,  
Osaka Prefecture, Japan (1989) by  
Tadao Ando.

excellent indoor environmental quality (Gillet, 2013, p. 8); an aim that should be a strong incentive for professionals to create the best conditions possible.

*"During the last century, the scientific approach for managing the indoor environment merely focused on single components (thermal comfort, light, air quality and noise) and, to some extent, on interrelations between these components in the bottom-up approach."* Bluysen (2009, p. 95)

### **The quantification of life**

Invention of the first technological innovation of the industrial revolution around the 1900s, electrical lighting and heating/cooling, made it possible to create artificial improvements to the indoor environment, which previously had been determined primarily by the temperament of climate, and with this offset efforts to improve indoor environment in buildings has been developing since (Hawkes, 2008; Bluysen, 2009). Hawkes (2008, p. 24) points out that these inventions mark the opportunity to redefine relationships between climate and architecture and thereby created a fundamental change in architecture which was characterized by Lewis Mumford as *'the quantification of life'*. The shift created the foundation for standardisation and a turn toward regarding technical aspects superior. Pallasmaa argues:

*"In becoming a specialist profession, architecture has gradually detached itself from its intentional background, evolving into a discipline more and more fully determined by its own rules and value systems. Architecture is now a field of technology that still ventures to believe itself a form of free artistic expression"* (2012a, p. 87)

Hence, many of the references encountered entail that sensuous qualities are also a central part of indoor environment; Bluysen even point out:

*"In fact, historically, these parameters received the most attention when designing a building"* (2009, p. 4).

Nowadays, indoor environment is described and defined in numerous texts and standards as is compiled of a range of aspects and though a bit differently named the various definitions includes the four themes: thermal comfort, indoor air quality, noise and light. (Olesen et al., 2013; EN 15251, 2007; Andersen, 2012; Gillet, 2013; Ruck, 2000; Bluysen, 2009; Steemers and Steane, 2004) To the four aspects belong precise definitions on what these include and how analysis and assessment is prepared, presented and rated; mostly these are presented in quantitative ways yet also including qualitative aspects.

Indoor environment is central to creating comfortable and liveable homes (e.g. Andersen, 2012; Hau, 2011; Bluyssen, 2009; Steemers and Steane, 2012; Pallasmaa, 2012a; Hawkes, McDonald and Steemers, 2002) and in a time where focus to a wide extent is on reduction of energy consumption and weighing environmental footprints focus tend to flicker away from exactly this primary aspect of building houses: creating homes and thereby establishing environments for people to unfold their lives in (Frampton, 1997; Beim, 2004; Hansen, 2010; Olesen et al., 2011b). With increasing legislative demands for achieving high standards with respect to energy performance (mainly based on nationally determined energy codes such as e.g. BE10 in Denmark), environmental impact (environmental assessment systems such as e.g. BREEAM, LEED, DGNB, Green Star, CASBEE, etc. (Edwards and Maboni, 2013)) and indoor environmental performance (Olesen et al., 2013b; EN 15251, 2007) the interrelatedness between the independent factors become increasingly sensitive and interdependent. Thus, separate standards, legislation and specialist professionals seemingly pull these further apart. The consequence is that spotlight aspects (the vigorous energy and environment) receive primary attention, while the sensitive indoor environment is thrown in the background. Hawkes (2008, p. xiii) expresses concern about primary focus on quantitative:

*'(...) the emphasis on the quantitative as the principle object of environmental design, around precisely the conflict of the measurable and the unmeasurable (...) I aim to develop an account of the environmental strategies adopted by important architects (...) I hope this will demonstrate that quantification and mechanization may co-exist with a poetic interpretation of the nature of the architectural environment.'*

Hau (2001, p. 19), thus, consider the technical aspects related to the basic level of indoor environment while the more qualitative aspects are icing on the cake: *"Standards, norms, and instruction ensure a basic level of indoor climate but variation, nuances, and possibility for self-regulation increase comfort and well-being are often characteristic to the best works of architecture."*

Eiler-Rasmussen (1989) reflects on this duality of quantitative and qualitative with regards to exploring daylight and he accentuates this to explain the concept of good daylight to him:

*'This is necessary, as today people are most occupied with the amount of light, with the quantity. If one thinks he cannot see well, he requires more light. And then, it may not help. Because when it comes to daylight, quantity is not nearly as important as quality.'* (Rasmussen, 1989, p. 191)



## 1.4 Delimitation

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*Architecture is a field constituted by multiple knowledge fields. Aspects to pursue in enquiring sustainable architecture are extensive. In a unique set up like the one provided here the array of possible ways to lead the research can seem innumerable. Therefore, delimitation is a necessary cause in order to make the project amenable.*

### **Three Model Home 2020**

This enquiry studies three Model Home 2020 homes in use. LichtAktiv Haus in Wilhelmsburg in the outskirts of Hamburg, Germany; Sunlighthouse in Pressbaum near Vienna in Austria; and Maison Air et Lumière in Verrieres le Buisson near Paris in France. The reason for enquiring these houses is timing in completion of construction and inhabitation.

### **Sustainable homes in-use**

There are many aspects (really interesting aspects) of these Model Home 2020 houses, in their designs, design processes, and design teams, construction and so forth. However, focus through this enquiry is on in-use situations.

### **Occupants and selection of these**

With an in-use set-up where real families inhabit the Model Home 2020 houses follow a ray of ethic issues. Through this research it was not possible to affect selection processes and timing for occupation of the homes

### **Focus on Indoor Environment**

The vision of Active House is based on the unity of Energy, Indoor climate and Environment. This research mainly includes aspects on Indoor Environment.

### **Excluding local and national perspectives**

The three houses are developed and built by different teams in different countries on different plots. This creates a ray of national and local aspects to consider, but these aspects are not integrated as central to this enquiry.

### **No comparing the projects**

Due to the variety of variables in the process of composing the buildings the thesis bears no intentions of comparing the different projects. That would not make sense in the light of the nature of the present enquiry.

*Opposite page (17)*

### **III. 1.4.1. Maison Air et Lumière**

*View to the oblique ceiling in the south facing children's room in. Roof windows are integrated in all ceiling surfaces and drag in daylight of both diffuse and directed character; adding to the perceived nature and diversity of the space and good distribution of light.*

## 1.5 Aim and Research Questions

---

The purpose of this research is to establish a mixed method based model for enquiry of sustainable homes in use. The intention with this model is to capture more aspects of sustainable life-form but merely the technical measurable ones, which development of sustainable architecture is mainly driven by today.

Through this enquiry focus is on establishing a more common language on knowledge about user perspectives, perceptual and technical qualities. The research enquires sustainable homes with an attempt to unfold the multiplicity and complexity of sustainability in a home perspective in the context of built environment. Thereby, it is central to develop a more holistic approach to enquiry of sustainable homes in use, that puts the user of the building in centre to ensure that perceived qualities and technical abilities supplement each other in establishing the best possible built environments for the future.

The central research question is thus:

- I. *How can a model for enquiry of sustainable homes based on a mixed methods approach include occupant perspectives, perceptual quality and technical ability; so the approaches supplement each other and establish a more complete illustration of the sustainability unfolded?*

To explore and unfold aspects of the overall research question, three research questions based on the themes for research are formulated:

- II. *How are everyday encounters with sustainable functionalism perceived by occupants, and what aspects does this bring to an automated, sustainable life-form which is probably a circumstance of the future?*
- III. *Aspects of perceived quality are central to create value for human beings in the built environment of the future, but how can perceived quality in sustainable architecture be registered, analysed, weighed up and conveyed without losing their qualitative nature?*
- IV. *How can indoor environment in sustainable homes be enquired through respectively occupant perspectives, perceptual quality and technical ability; so the approaches supplement each other and establish a more complete illustration of the sustainability unfolded?*





PART II |

Theory & Method

## 2.1 Mixed Methods research design

---

*Previous spread()*

*ill. 2.1.0. Shades of light*

*Diffuse light enters through roof windows in the oblique ceiling surfaces in Maison Air et Lumière. The soft tones of light add to the experience and lends a special feeling to twilight hours.*

Sustainable architecture is a complex field of knowledge occurring in symbiosis between technical, functional, physical, physiological, perceptual and sensuous qualities. Therefore it is founded on various philosophies and sciences. As unfolded through the chapter in *State of the Art on enquiry in sustainable homes*, mixed methods research approaches are increasingly commonly applied to enquire sustainable buildings. To meet the complex nature and multi-disciplinary foundation inherent in sustainable architecture, this research also follows a mixed methods research design elaborated through the following.

### Mixed methods research

Mixed methods research is an approach to exploring subjects from a mixed methods perspective and thereby creating the possibility to illuminate the same problem from various perspectives simultaneously making the approaches support each other. This interpretation is supported by Rabinowitz (2013) who believes that quantitative and qualitative methods are complementary as each has strengths and weaknesses the other go not have. Thereby together they can form a clearer illustration of the circumstances than either of them would be able to alone. Within the discipline of mixed methods research there are various definitions and approaches which cannot be described here; common to them is that they reflect different ways of consolidating the methods in used. (e.g. Johnson, Onwuegbuzie and Turner 2007; Creswell 2009; Yin 2009; Ragin and Amoroso 2011; Brymann 2009; Tashakkori & Teddlie, 1998) Creswell and Plano Clark (2007) stress that the mixing of methods must happen through all stages of research through data collection and analysis and accentuate that the combination of quantitative and qualitative approaches is the central premises for establishing an enhanced understanding of the research problem than either on method or approach would be able to establish alone.

In an online lecture Creswell (2013), who is considered a main figure in formulating mixed methods research summons up: “(...) in the simplest way of thinking about it is just simply putting together the stories of people’s lives as well as the numbers, the statistics, of what occurs (...) The whole idea is that combining both the statistics and the stories gives us a more complete understanding of our research problem than just one by itself.”

## Thoughts on a Model for Enquiry of Sustainable Homes

Through the following pages a Mixed Methods research design is specified based on Creswell's Framework for Design (Creswell, 2009, p.5). The following pages will unfold Philosophical Worldviews, Strategies of Enquiry and Research Methods that form the pillars of the research design structure. Ill. 2.1.1. illustrates a Framework for the Design by interconnecting Philosophical Worldviews, Strategies of Enquiry and Research Methods and thereby framing the research design.

This design is the foundation for the later development of a Model of Enquiry though Part IV. The research is based on mixing research in design and research through design (Frayling, 1993; Archer, 1995; Friedman, 2003; Groat & Wang, 2013) as the perspective is based on an iterative process (Hansen & Knudstrup, 2008) of shifting between theory and practice based explorations. The nature of the research followed though the work can best be described as Action Research as defined by Archer (1995) as it pursues testing new ideas and procedures to produce communicable knowledge.

The intent of compiling such a research design is to illustrate diverse values of sustainable life and thereby support both perceived and technical aspects of sustainable architecture.

### Philosophical Worldview

*Pragmatic*  
- Empirical analytical  
- Positivist  
- Phenomenological  
- Hermeneutics



### Research Designs

*Mixed Methods*

### Research Methods

- Technical measurements  
- Questionnaire  
- Blog research  
- In-situ research

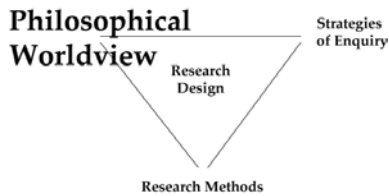
### Strategies of Enquiry

*Concurrent  
transformative  
design*

### ill. 2.1.1. A Framework for Design

*The Interconnection of Worldviews,  
Strategies of Enquiry, and Research  
Methods specified on present thesis;  
based on (Creswell, 2009, p. 5)*

## 2.2 Philosophical Worldviews



### ill. 2.2.1. Philosophical Worldview

*The diagram illustrates that this chapter is concerned with the Philosophical World view; one of the cornerstones of the research design.*

*The Philosophical Worldview is founded on a Pragmatic worldview – while the branches are based on respectively Empirical-Analytical, Positivist, Phenomenological and Hermeneutic worldviews.*

### Pragmatic Worldview

The thesis is based on enquiring sustainable architecture through respectively technical ability, occupant experiences and perceived quality (Olesen et al, 2011a; Olesen et al., 2013a; Olesen & Knudstrup, 2013b; Olesen et al., 2013b).

A pragmatic worldview occurs from situations, actions and consequences rather than predetermined conditions. Thereby pragmatics content that philosophical aspects are best viewed in terms of their practical use. Creswell lists a ray of characteristics to pragmatist worldview, among these he states that (Creswell, 2009, p. 11):

*“Truth is what works at the time. It is not based in duality between reality independent of the mind or within the mind. Thus, in mixed methods research, investigators use both quantitative and qualitative data because they work to provide the best understanding of a research problem.”*

Pragmatics focuses on using applications that works best at the time. Rather than focusing on methods that belong to a certain knowledge field or science branch, emphasis is on the research problem. Any approach available is used to illuminate and understand the problem. Thereby, the focus is on the *what* and the *how* to research (Creswell, 2009) (Tashakkori & Teddlie). Creswell accentuate that pragmatism creates access to multiple methods, different worldviews and different assumption to the mixed methods researcher. This also goes for different kinds of collection, analysis and treatment of data (Creswell, 2009).

As this research focus on exploring a more holistic approach to enquiry of sustainable homes a pragmatic worldview is obvious as a base to tie together different perspectives. Four scientific branches of knowledge are enquired through the thesis. Amongst these is technical ability, occupant perspectives and perceived quality. Thereby, application of multiple methods is an apparent course and thereby the study commits to a range of worldviews relating to the different explorations respectively *Empirical-Analytical*, *Positivist*, *Phenomenological* and *Hermeneutic*. The four worldviews all stem from an empirical worldview which states that knowledge origins from sensory experience. (Groat & Wang, 2013; Bryman, 2008; Creswell, 2009; Gadamer, 2004)

*“My perception is [therefore] not a sum of visual, tactile, and audible givens: I perceive in a total way with my whole being: I grasp a unique structure of the thing, a unique way of being, which speaks to all of my senses at once.”*

Maurice Merleau-Ponty (1964, p. 50)

### Empirical–Analytical Worldview

Technical abilities of the houses are looked at through an *Empirical-Analytical* worldview. This view is characterised by its quantitative nature and hold to the belief that knowledge of the whole can be broken down into pieces in which the same knowledge can be found from the parts. Focus is on measuring and quantifying phenomena. (Groat & Wang, 2013; Bryman, 2008; Creswell, 2009)

### Positivist Worldview

Occupants perspectives on life in sustainable homes are explored through two approaches, respectively a questionnaire and a blog approach. Questionnaire approach is founded on a *Positivist* worldview. In *Positivism* the basic premise is that on empirical experience can bring knowledge. This is rooted in an empirical–analytical worldview. The positivist worldview is a reaction to the metaphysical and superstitious and thereby builds on the foundation of reality and science. The *Positivists* believe that knowledge is confirmed through the senses and is based on methods and models from natural-science. (Boolsen, 2009; Brinkmann & Tanggaard, 2011; Creswell, 2009)

### Phenomenological Worldview

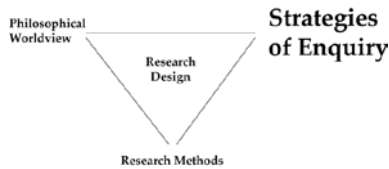
The *Phenomenological* worldview began with Kant and Hegel in 18<sup>th</sup> century and later Husserl and Heidegger (Heidegger, 1953). *Phenomenological* research aims at examining meaning of life through lived experiences of individuals and explores their inner worlds; describe experiences as they are lived through identifying common meanings and relational themes. (Merleau-Ponty, 1945; Merleau-Ponty, 1964)

### Hermeneutics Worldview

The other part of occupant perspectives is enquired through a blog approach – an approach rooted in the *Hermeneutic* worldview which is a branch of phenomenology (Heidegger, 1953; Gadamer, 2004; Perez-Gomez, 1985). The fundamental premise for Gadamer's hermeneutics says that truth can be reached only by understanding experience. This understanding is not fixed but constantly changing always indicating new perspectives where the central thing is to unfold the nature of individual understanding. (Gadamer, 2004)

## 2.3 Strategies of enquiry

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### *ill. 2.3.1. Strategies of Enquiry*

*The diagram illustrates that this chapter is concerned with the Strategies of Enquiry; one of the cornerstones of the research design.*

*The mixed methods strategy of enquiry is a concurrent triangulation design.*

Mixed methods research can be many things and defining the strategy of enquiry is strongly related to focus and approach of the work. This is so to say determining how the mixing of methods is approached and there are many ways of creating Mixed Methods designs (Johnson, Onwuegbuzie and Turner 2007) Creswell & Plano-Clark (2011) define four strategies and two sub strategies while Bryman (2006) lists 18 ways of combining quantitative and qualitative research, while Greene, Caracelli and Graham (1989) define five.

### Concurrent triangulation design

This research enquiry is based on a so-called concurrent triangulation design strategy. This strategy is characterised by applying two or more methods to confirm, cross-validate, or substantiate findings through concurrent data collection. The purpose behind this strategy is to overcome a weakness in applying only one method with the strengths of another. (Creswell & Plano-Clark, 2011; Creswell, 2009 Bryman, 2006; Greene, Caracelli and Graham, 1989)

Following characteristics identified by Creswell & Plano-Clark (2011, pp.53-106):

- Triangulation seeks convergence, corroboration, and correspondence of results from the different methods.
- Triangulation or greater validity refers to the traditional view that quantitative and qualitative research might be combined to triangulate findings in order that they may be mutually corroborated.
- Concurrent quantitative and qualitative data collection, separate quantitative and qualitative analyses, and the merging of the two data sets
- Used when needing a more complete understanding of a topic
- Used when needing to validate or corroborate quantitative scales

Through this enquiry four methods are used to explore respectively technical ability, user perspectives and perceived quality in sustainable homes. The strategy for enquiring technical ability is a qualitative methodology based on an experimental approach, as the houses are built and thereby can be enquired in full scale and in their natural contexts and environments. Several strategies are related to the qualitative approaches. Questionnaire research is based on grounded theory approach (Boolsen, 2006) and blog and field research are based on strategies mixing narrative and phenomenological research strategies (Groat & Wang, 2013; Brinkman & Tanggaard, 2010).

The strategies are elaborated in the following chapter on research methods.

## 2.4 Research Methods

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### Quantitative methods

For decades technological improvement was the main driver for advance of sustainable architecture, why development of enquiry tactics as a natural consequence grew from the technologically based sciences as found through State of the Art studies (Edwards, 2010; Laurant and Marsh, 2009).

### Technical measurements

Measurements are carried out as long term measurements using sensors installed in all spaces in the house in a specifically selected position in each of the rooms. In ISO 7726:1998 Ergonomics of the thermal environment – Instruments for measuring quantities (ISO TC 159/SC 5/WG 1, 1998) the derived physical quantities characterizing the environment are described as:

*‘(...) a group of factors of the environment, weighted according to the characteristics of the sensors used. They are often used to define an empirical index of comfort or thermal stress without having recourse to a rational method based on estimates of the various forms of heat exchanges between the human body and the thermal environments, and of the resulting thermal balance and physiological strain. Some derived quantities are described in the specific standards as they apply and where measuring requirements are included.’ (ibid, p6)*

### Qualitative methods

Qualitative methods can supplement quantitative research methods by providing description of phenomena based on perception and experiences. Often, qualitative (semi-structured) interviews are applied as an approach appropriate for exploring subjects brought up during the session (Kvale, 2009). However, in the current setup there is the challenge that the houses to undergo enquiry are situated across Europe in Germany, Austria and France while the researcher is native Danish. This creates inherent language barriers. Interview sessions would cause travelling, translation and transcription which are all time consuming practices in conflict with the aim of establishing a simpler and more time efficient approach. Another dimension is the aspect of variability and an intention to explore possible aspects of variation in these houses. Uncovering variability over time in the houses require repeated rounds of interviewing – adding to the extent, resource demands and costs of the enquiry.

For these reasons, the intended qualitative interviews (Olesen et al., 2011a; b) are replaced by respectively questionnaire and blog approaches.



#### ill. 2.4.1. Research Methods

*The diagram illustrates that this chapter is concerned with the Research Methods; one of the cornerstones of the research design.*

*The mixed methods strategy of enquiry is created from four research methods, respectively a quantitative one which is technical measurements; and more qualitative ones which are respectively questionnaire, blog and In-situ research.*

*Template table for overview of measurement points and units can be found in Appendix I*

*Further reading on enquiry through technical measurements Olesen et al., 2014, Part IV from page 43 and forward and Month measurement reports referred to in the Bibliography PART V.*



*Questionnaire template can be found in Appendix II.*

*Further reading on enquiry through questionnaire can be found in Olesen et al., 2013; Olesen et al., 2014 and Part IV from page 51 and forward.*

## Questionnaire research

As illustrated in State-of-the-Art on enquiry of sustainable architecture technical measurements are commonly supplied by questionnaire research. Questionnaire is managed as email survey. The format is directed by a longitudinal design where occupants answer the questionnaire four times during the one year test period (Bryman, 2008; Brinkman, 2010; Boolsen, 2006). Questionnaires are translated to native language (Bryman, 2008). Questions posed in the questionnaire use respectively three; four and five point Likert scales (Likert, 1932).

An immediate advantage of replacing interview with questionnaire is that this meets language barriers, reduces costs and timely resources, and is more easily distributed several times. Also, occupants have greater freedom in when (and where) they wish to answer to the scheme, within a given time frame. This provides opportunity to collect data on a seasonal basis and thereby explore if occupants experience change relating to seasons.

A downside to replacing the qualitative interview with a questionnaire is the shift from qualitative to more quantitative methodology. Also, it is difficult to be aware how the respective occupants interpret the respective answering possibilities of the Likert scale creating an uncertainty to the survey. Thereby, some apparent qualities vanish, such as statements from users and elaboration on themes of interest. Also, an aspect of spontaneous experience is difficult to capture through questionnaires. To meet the wish for unfolding occupant experiences in a freer format than the strict and predefined questionnaire approach; and enable inclusion of more narrative character, the research introduces a blog approach.

## Blog

Blog is an online media, as described by the Oxford Dictionary "...a personal website or web page on which an individual records opinions, links to other sites, etc. on a regular basis". Wikipedia.org elaborates this description: "A blog (or weblog) is a website which is regularly updated with short texts (messages or lines) with the most recent at the top. There is often the possibility that readers can comment on individual posts. Contents may vary from the personal diary-like to the political debating or thematic. A blog is often linked to a person but can also be shared by a larger group. He who writes / edits a blog is called a blogger. Bloggers write with fairly regular intervals, say every week. In a weblog blogger writes often about her life just like in a diary. It can also be about a particular subject."

A blog can roughly be characterised as a qualitative method in line with semi-structured interviews (Kvale, 2009), open-ended interviews (Brinkmann &

*Web-addresses to the respective blogs of the houses can be found in Appendix III.*

*Further reading on enquiry through blogs can be found in Olesen et al., 2013; Olesen et al., 2014 and Part IV from page 51 and forward.*

Tanggaard, 2010), Cultural Probes (Alexandra Institute, 2012) or to some extent Open questionnaires (Boolsen, 2008); methods all belonging in social and anthropological sciences. The blog has possibilities of containing qualities similar to the data from semi-structured interviews described by Kavle (2009) as an *“interview with the purpose of gathering descriptions of the Interviewees lifeworld with the purpose of interpreting the meaning of the described phenomena”*, and cultural probes described by Alexandra Institute (2012) as *“a method where users themselves are helping to collect data on their daily lives”* without being demanding or time consuming for the researcher, and being a free medium for the occupant who can decide for him/herself how much efforts to put in.

Thereby, questionnaire survey is supplemented by this continuous, free format, voluntary approach and occupant perspective are illuminated through respectively quantitative and qualitative approaches. (Olesen et al. 2013)

### In-situ

With the intent to approach enquiry of sustainable homes in a more holistic and balanced way, this work integrate perceived qualities to explore sustainability from more than the ‘traditional’ engineering perspective. To explore and enquire perceived quality the researcher must perceive by studying settings or phenomenon embedded in its real-life context. (Groat & Wang, 2013; Yin, 2009)

Field research is about going out in the field with the purpose of collecting data employing variable methods such as direct observation, participation studies, analyses of documents, self-analysis; methods which are often characterized as qualitative but also may include quantitative aspects (Bryman, 2008; Creswell, 2009; Groat & Wang, 2013; Yin, 2009). In the classical understanding the methods are anchored mainly in the ethnographic and anthropological sciences – sciences that study people and cultural phenomena and additionally also in architectural science. In this case, the area subject to research is the sustainable houses. As Pink (2007) points out performing field research is *‘a unique and personal experience’* which different researcher will most likely approach differently though using the same methods. Through this enquiry both terms field research and In-situ research are used to embrace this bodily encounter.

Focus though In-situ research is on exploring sustainable houses, their perceptual qualities and cultural phenomena; this is for instance be relations between house and surrounding nature, interplay between houses materials, or maybe narratives in the way daylight with is accompanying shadows enter through the skylights. Thereby the research combines enquiries of drawings, rendering and stem-data with bodily and sensuous encounters, observation, photo documentation and experience notes within the built environment.

*Further information on the In-situ approach can be found in Appendix IV.*

*Further reading on how this enquiry approach is developed and explored can be found in Olesen & Knudstrup, 2013a, Olesen & Knudstrup, 2013b and Part IV from page 55 and forward.*





PART III |

Model Home 2020







CarbonLight Homes, Ketting, UK  
VELUX | New double-row-house



Photo: Gitta Gylling

Home for Life, Lystrup, Denmark  
VELFAC | New residential house



Photo: Gitta Gylling

LichtAktiv Haus, Wilhelmsburg, Germany  
VELUX | New double-row-house



Photo: Gitta Gylling

Haus der Zukunft, Regensburg, Germany  
SONNENKRAFT | New house



Photo: Gitta Gylling

Maison Air et Lumière, France  
VELUX | New residential house



Photo: Gitta Gylling

Solar Aktivhaus, Kraig, Austria  
SONNENKRAFT | New house



Photo: Gitta Gylling

Sunlighthouse, Pressbaum, Austria  
VELUX | New residential house

### 3.0 Three test houses and their occupants

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#### From vision to reality

In line with the statement by engineer and inventor of the VELUX roof window Willum Kann Rasmussen (Boje, 2004): *'One experiment is better than a thousand expert views'* the idea of the Active House was taken from vision to reality. Through 2008-2012 eight demonstration buildings are materialized - eight experiments - designed and constructed in line with the Active House vision. The first experiment realized is the new-built single-family house *Home for Life* which opened in 2009 with VELFAC as the building owner. Following seven buildings are constructed – two new-built single-family houses with SONNENKRAFT as building owner and the final five buildings whereof one is a new-built office building, one renovation of a single-family house and four new-built single-family houses with VELUX as building owner. (Olesen, 2011)

#### Model Home 2020

Six of the demonstration buildings are in the VELUX based ModelHome2020 project. These are part of a wider company strategy of developing and researching products and solutions for future energy and livability challenges. The intent with the *Model Home 2020* strategy is to combine excellent indoor environment with high quality homes mainly driven by renewable energy sources as contextually optimized design solutions (VELUX, 2010). Thereby, the houses are designed, built and constructed as state-of-the-art homes with the newest technological developments and high quality materials. These houses are built to explore possibilities in future technical as well as perceived sustainability. All houses have automatic systems installed as to optimize indoor environmental conditions, for instance by automatically opening and closing windows to air out exhaust or warmed air, pull down solar shading to prevent too much solar gains or shut windows when raining. Sensors are installed in each house in each of the rooms to register indoor environment conditions (temperature, CO<sub>2</sub> levels, relative humidity, lux) and regulate based on these values. A weather station is installed on the roof top of the house to register outdoor weather conditions (temperature, rain, global illuminance, hours of sunshine and wind direction). These data are used to adjust the indoor environmental conditions to the comfort of the occupants. Three *Model Homes 2020s* houses LichtAktiv Haus (Germany), Sunlighthouse (Austria) and Maison Air et Lumière (France) and their occupants are subjects to this research. These are introduced respectively below. (Olesen, 2011)

#### Previous spread (31-32)

##### ill. 3.0.0. Active surfaces

*The photo is of the south-west facing roof surface of Sunlighthouse in Austria. The entire surface is utilised for harvesting energy through active as well as passive means.*

#### Previous page (33)

##### Ill. 3.0.1. Map of houses

*The illustration is a map showing the distribution of single-family demonstration houses across Europe developed on basis of the Active House Vision.*

*The houses are:*

*Home for Life, Lystrup, Denmark (2009), VELFAC & VELUX*

*Licht Aktiv Haus, Wilhelmsburg, Germany (2010), VELUX*

*Haus der Zukunft, Regensburg, Germany (2010), SONNENKRAFT*

*Solaraktivaus, Kraig, Austria (2010), SONNENKRAFT*

*Sunlighthouse, Pressbaum, Austria (2011), VELUX*

*Maison Air et Lumière, Verrières-le-Buisson, France (2012), VELUX*

*CarbonLight Homes, Kettering, United Kingdom (2012), VELUX*

*The houses have all been part of the work carried out in relation to this thesis, thus only three houses are enquired through the testing through the following chapters. These houses are presented on the following three spreads.*

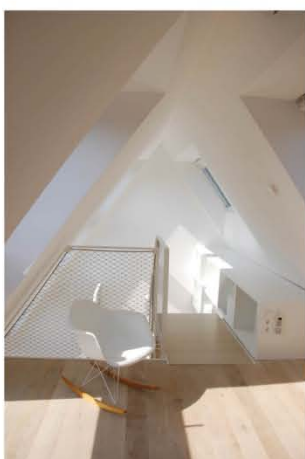
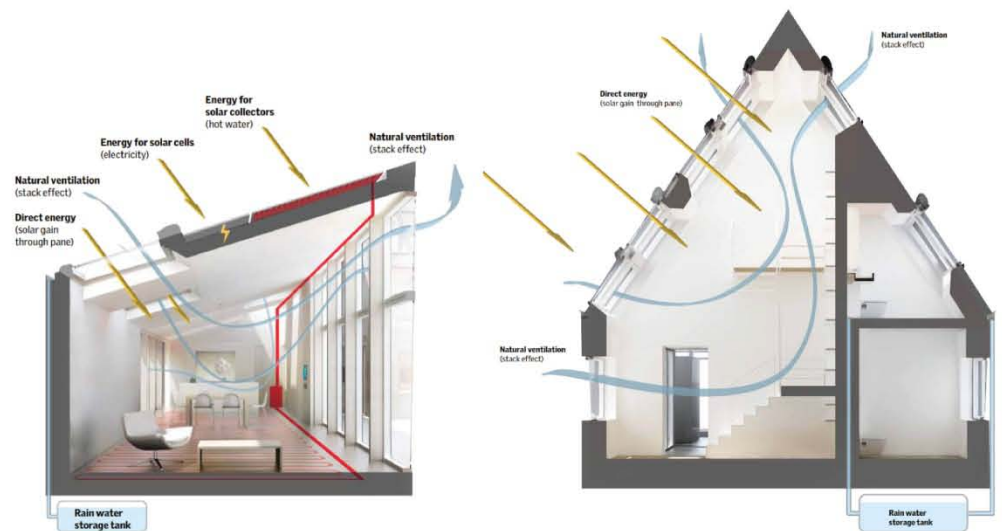
# LichtAktiv Haus

*Wilhelmsburg near Hamburg, Germany*

LichtAktiv Haus is situated in Germany in the suburb of Hamburg named Wilhelmsburg. The concept of the house is developed in a student competition at the Technical University of Darmstadt with the winner architectural student Katharina Fey. The concept was further refined in collaboration between Fey and architect Jan Ostermann and completed in 2011 with VELUX as project leader. The house consists in half a Settlers double house with an attached new building all in all 189 m<sup>2</sup> with 100m<sup>2</sup> façade and roof windows, 22.5m<sup>2</sup> solar collectors and 75m<sup>2</sup> of photo voltaic. The house is designed to produce all the energy it uses on site (see Appendix III for further information on the house).

## Family Oldendorf

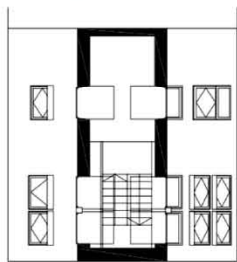
The Oldendorf family consists of Christian (40 years old), Irina (38 years old), Lasse (9 years old), Finn (7 years old). The test family live in the house in a two year test period (1<sup>st</sup> December 2011 – 30<sup>th</sup> November 2013) while present project follows the family from June 2012 till May 2013



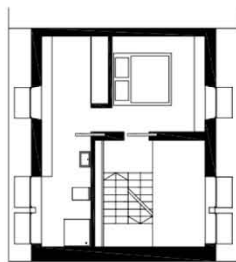




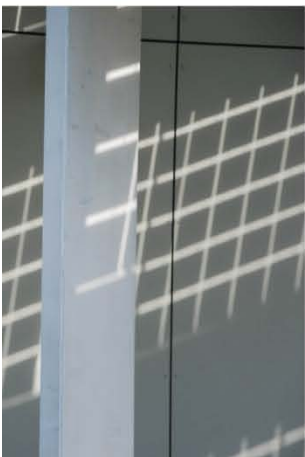
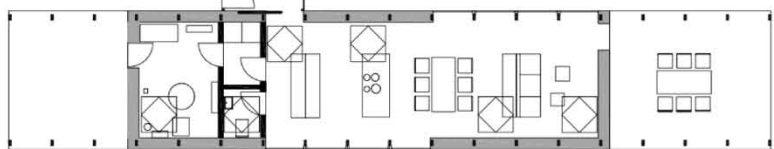
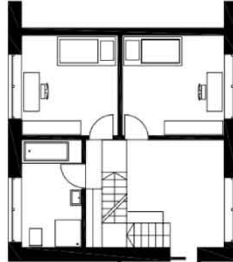
Second floor



First floor



Ground floor





# Sunlighthouse

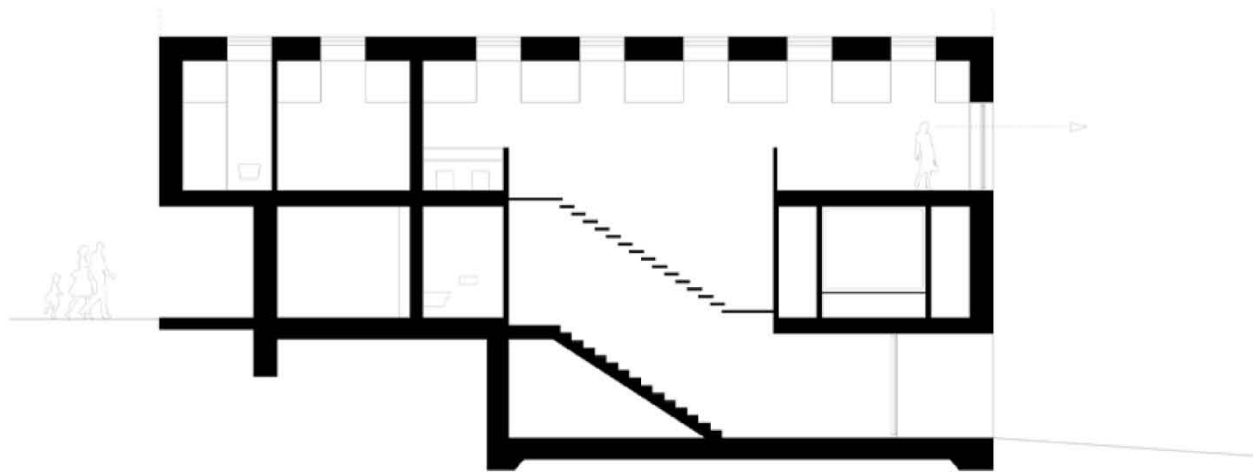
*Pressbaum near Vienna, Austria*

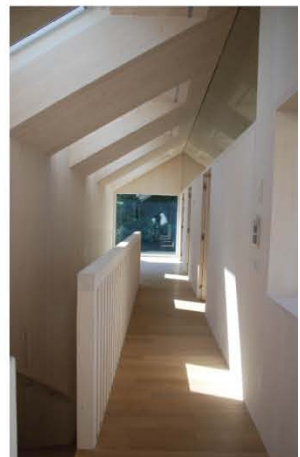
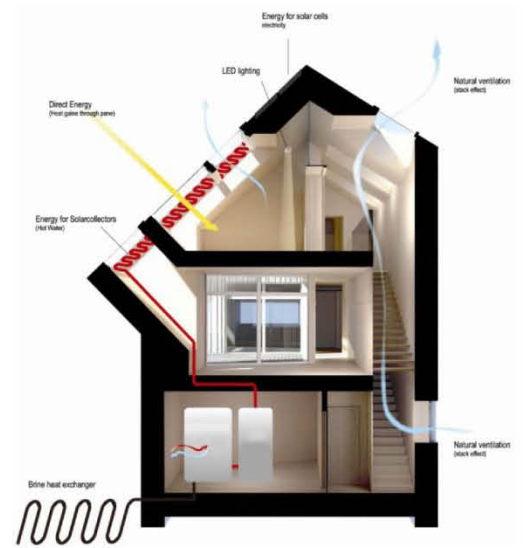
Sunlighthouse is developed by Hain-Troy Architects to respond to the challenges of the sloping plot: "a very steep and leafy slope in partial shade facing south-east towards the Vienna woods. Shadows cast by the nearby mountain have been countered in the living room by elevated roof windows, which allow light to fall into the depths of the room. The kitchen and dining areas are gathered around a protected, south-west-facing space. Windows – both roof and facade windows – are strategically positioned so as to provide a particular view while maximising passive solar energy gains, while also emphasising the character of the house. All of these measures combined make for an unusually high proportion of daylight." (brochure)

The house is a new-built house in three storeys all in all 304 m<sup>2</sup> with many façade and roof windows, and solar collectors and of photo voltaic for renewable energy production on the roof; designed to produce all the energy it uses on site.

## Family Dorfsetter

Family Dorfsetter Ludvig (32 years old), Yasmin (30 years old), Alfred (4 years old), Johann (2 years old). The test family live in the house in a one year test period (1<sup>st</sup> March 2012 – 28<sup>th</sup> February 2013) while present project follows the family through the entire period from March 2012 till February 2013.





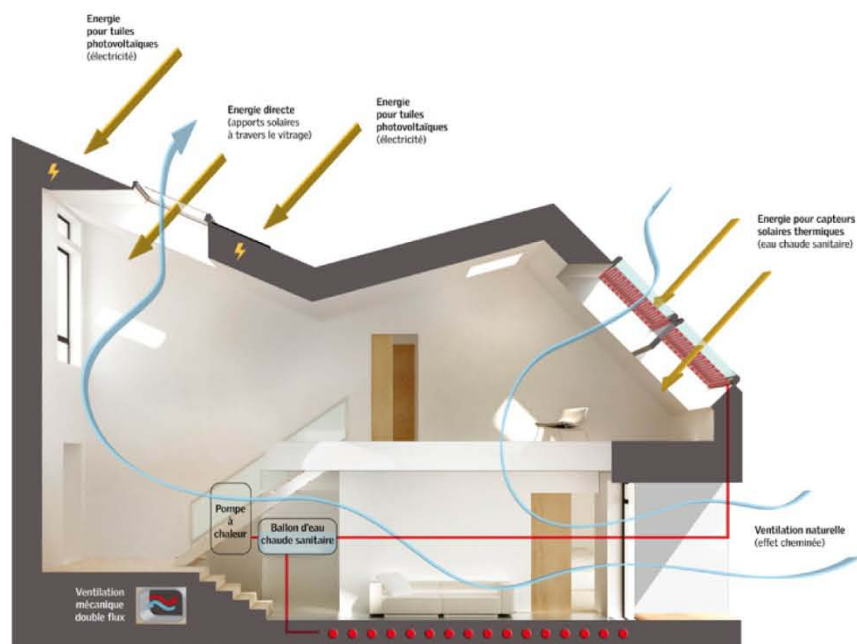


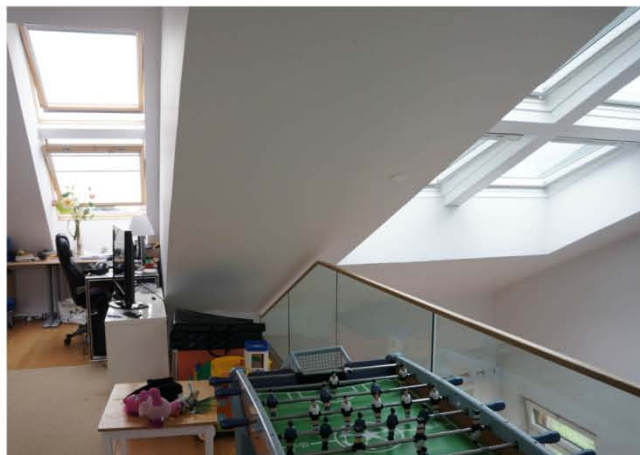
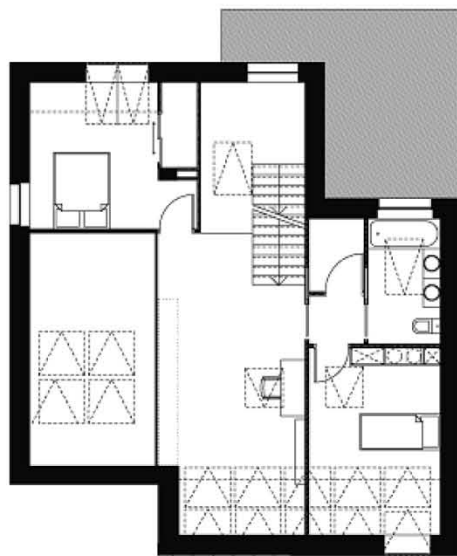
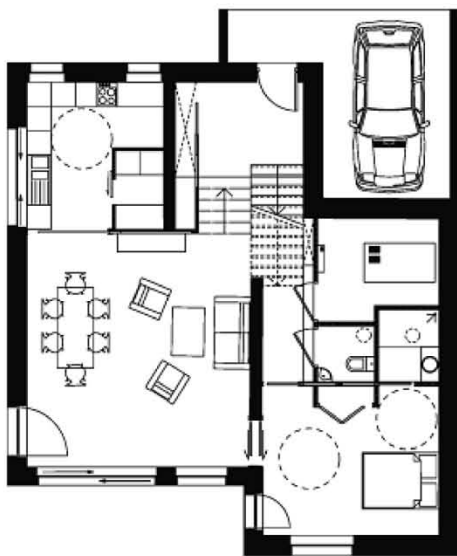
# Maison Air et Lumière

*Verrières-le-Buisson near Paris, France*

Maison Air et Lumière means 'house of light and air'. Focus is also on these aspects in the design which aims at creating balance and unity between an excellent indoor climate and low energy consumption. The house is oriented to harness sunlight for optimizing energy and daylight gains and quality in the house. The shape of the house is composed by modules of various shapes and volume and appears as three building blocks put next to each other – these blocks forms modules in an addition system enabling a range of different designs from the same basics. The house is 130m<sup>2</sup> with one roof sloping 45° for the 8.4m<sup>2</sup> solar collectors that heat the house and another sloping 25° for the 35m<sup>2</sup> of photo voltaics that produces electricity.

Maison Air et Lumière family Fabrice (35), Samantha (33) and their two children, Rayan (7) and Ismaël (3), will live in the house in a one year test period (1<sup>st</sup> September 2012 – 31<sup>th</sup> August 2013) while present project follows the family through the entire period.







The image shows a modern interior space with light-colored wood paneling on the walls and ceiling. The ceiling has a series of recessed rectangular sections. On the right, a window looks out onto a dense green forest. The overall aesthetic is clean and natural.

PART IV |

A Model for Enquiry



*Previous spread (41-42)*

***ill. 4.0.0. Material, light & view***

*Elements of light pine wood, shape, windows, diffuse and directed daylight and view into the deeply green treetops creates a unique effect of space in the upstairs hall of Sunlight house, Austria.*

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

Article #1:

Gitte Gylling Olesen, Mary-Ann Knudstrup, Per K. Heiselberg, Jens Christoffersen (2013)  
*Exploring a Model for Enquiry of Sustainable Homes through Indoor Environmental Aspects*  
Submitted to *Indoor and Built Environment*

Article #2:

Gitte Gylling Olesen, Mary-Ann Knudstrup, Per K. Heiselberg, Jens Christoffersen (2013)  
*Encountering Sustainable Functionalism: Feedback as a Method to Raise Awareness on Energy Use and Indoor Environment in Automated Homes.*  
Submitted to *Architectural Science Review*

Article #3

Gitte Gylling Olesen and Mary-Ann Knudstrup (2013) *Enquiring Perceived Quality in Sustainable Architecture: A More Tangible Approach*  
Submitted to *The Journal of Architecture*

## 4.0 Introduction

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Part IV covers the central part of the thesis and revolves around development of the Model for Enquiry of Sustainable Homes. The Part starts off by proposing a model based on the approaches identified through the previous chapter:

- I. *How can a model for enquiry of sustainable homes based on a mixed methods approach include occupant perspectives, perceptual quality and technical ability; so the approaches supplement each other and establish a more complete illustration of the sustainability unfolded?*

Following the proposed model is applied to empirical testing on three Model Home 2020 houses in-use. The empirical testing is a development process of both iterative and repetitive character which should be kept in mind when reading through the following pages. Through development and application of design, collection, treatment and dissemination the three research themes of interest are explored: *The Human in Centre*, *Perceived Quality* and *Perceived Indoor Environment*. The three research questions specified for these themes are:

- II. *How are everyday encounters with sustainable functionalism perceived by occupants, and what aspects does this bring to an automated, sustainable life-form which is probably a circumstance of the future?*
- III. *Aspects of perceived quality are central to create value for human beings in the built environment of the future, but how can perceived quality in sustainable architecture be registered, analysed, weighed up and conveyed without losing their qualitative nature?*
- IV. *How can indoor environment in sustainable homes be enquired through respectively occupant perspectives, perceptual quality and technical ability; so the approaches supplement each other and establish a more complete illustration of the sustainability unfolded?*

Following these enquiries methodologies, approach and the Model for Enquiry are reflected through discussion. Finally, the chapter is rounded off with presentation of the final *Model for Enquiry of Sustainable Homes*.



## 4.1 Developing a Model for Enquiry

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*To meet the complexity of the built environment and resemble different aspects that influence sustainable life-form this work include a range of knowledge fields and thereby also philosophical worldviews and methodological approaches (see PART II, pp. 23-32).*

### Holistic and balanced approaches

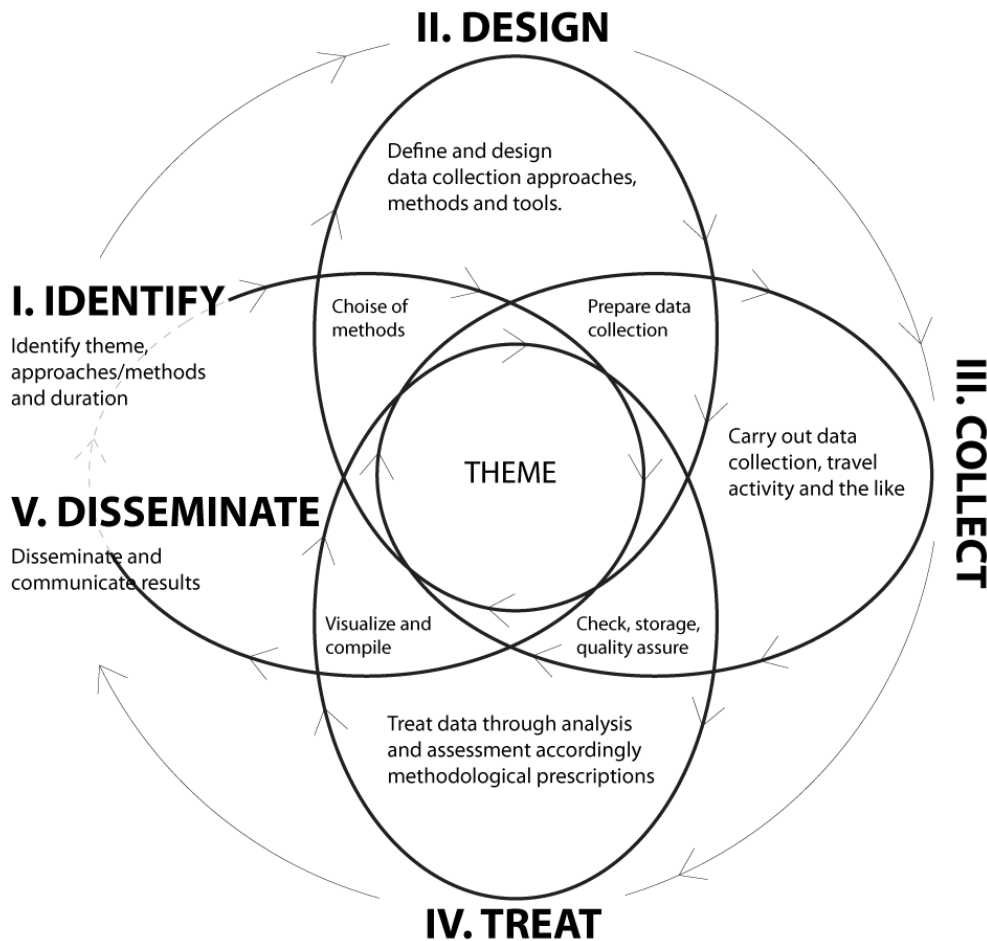
Development of sustainable architecture is moving in an increasingly holistic direction where an aim of creating balance is beginning to be reflected in enquiry methods (as shown through PART I, pp. 1-22). The foundation for development of the model is, accordingly, based on a holistic view point aiming to establish encounters in the sphere between empirical-analytical, positivist, hermeneutic and phenomenological worldviews (see PART II, pp. 27-28). The model represents a systematic methodological approach designed following a Concurrent Transformative Strategy of inquiry in a mixed methods setup (see PART II, p.29).

### Proposing a draft model for enquiry

The aim of the model is to create an approach to enquiry of sustainable homes which include dynamic in-use aspects through occupant perspectives based on questionnaire and blog research, perceptual qualities based on in-situ registration and technical ability based on measurements. The logic behind the model is to create balance between sciences and practice through a simplified model applicable to practice within limited resources which in addition scientifically well-founded, methodological accurate and supports validity. The model further built on an interest in uncovering and enquiring themes of interest rather than relating to one core scientific methodology.

The model is designed as a five phase structure embracing the respective phases: I) Identify; II) Design; III) Collect; IV) Treat and V) Disseminate. Focuses orbit around a theme which each step continuously consult through an integral and iterative process. The approach is inspired by respectively the iterative design process (Knudstrup 2006; Hansen & Knudstrup, 2007) and a basic understanding that the steps of the model must be consolidated before the next layer can be added or in this case the next iteration. Thereby, the model represents a dynamic process of movement.

The proposed model is illustrated in ill. 4.1.1. in shape of a flower diagram where the phases continuously consult the central theme of interest. The phases are elaborated through the following and each step through ill. 4.1.3.



*ill. 4.1.1. Proposed model*

The proposed Model of Enquiry illustrates the five step process of I) Identify; II) Design; III) Collect; IV) Treat and V) Disseminate knowledge from sustainable homes.

## Elaborating the five phases of the proposed model

### I) Identify

The initial phase identifies scope, aim and theme of interest. Scale of theme can vary accordingly demand; it can be an overall theme such as *Indoor environment* or a more particular one as for instance *thermal comfort*. This provides opportunity to apply the model on various scales. The theme selected establishes the frames for unfolding enquiry. Also, the initial phase identifies extent and duration of the enquiry and uncovers what methods are appropriate for holistic illumination of the theme within respective scientific approaches. Conceptually, any science, field of knowledge and methodological approach could be applied here; however, the basic format relies on four knowledge fields based on technical ability, occupant perspectives and perceptual quality.

## II) Design

The second phase includes design of data collection approaches based on the identified methods from phase one. This includes specification of templates through for instance formulation of questions, registrations points or values. The phase results in a pile of templates. Through this phase it is also essential to make planning and preparation for performing data collection. Agreements, permits, possibly contracts and other practical measures are made. It is also through this phase equipment for data collection is tested and preliminary studies are carried out so everything is in order for use.

## III) Collect

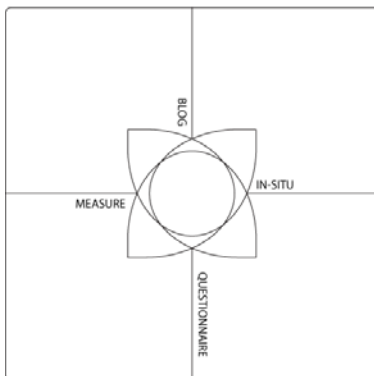
During the third phase data is collected. This can be carried out in numerous ways. Some types of data collection might require field trips, interview activity or live measurements while other are based on gather data off Internet or databases. With data collection follow check, control and quality assurance of the respective types of data. This is an essential phase to avoid bias or mistakes in the quantities of data and should be carried out as data collection is going on. If, for instance data are collected during an entire year, it is vital to check measurements equipment periodically to make sure that a meter or its connection to a database is not broken or lost. Collected data also need to be storage properly in a database of system accessible to all parties of the enquiry. Some data might possible need alignment in form of translation or the like.

## IV) Treat

During phase four data are treated though analysis and assessment accordingly their specified methods evolving around the theme in centre. The integral mixed methods approach is underlined though constant attention towards the central theme where collation of the approaches are pursued. This implies a cross scientific perspective through treatment so that findings, learning, and knowledge are explored in an explanatory manner where the methods can support treatment across the various sets of data.

## V) Disseminate

Phase five is dissemination of the enquiry. This is the phase though which the findings of the effort are released through carefully communicable knowledge. Results should be disseminated together in a common approach. For this purpose, this method suggests a diagram that can communicate findings from four methods on the same theme concurrently (see figure 4.1.2.). The diagram has one field for exemplifying findings; this might be a figure, picture or quote; one field for stating the rating of the specific enquiry; and one field for an average of ratings. The diagram is applied in Olesen et al. (2014) and on pages 69-71 in this thesis.



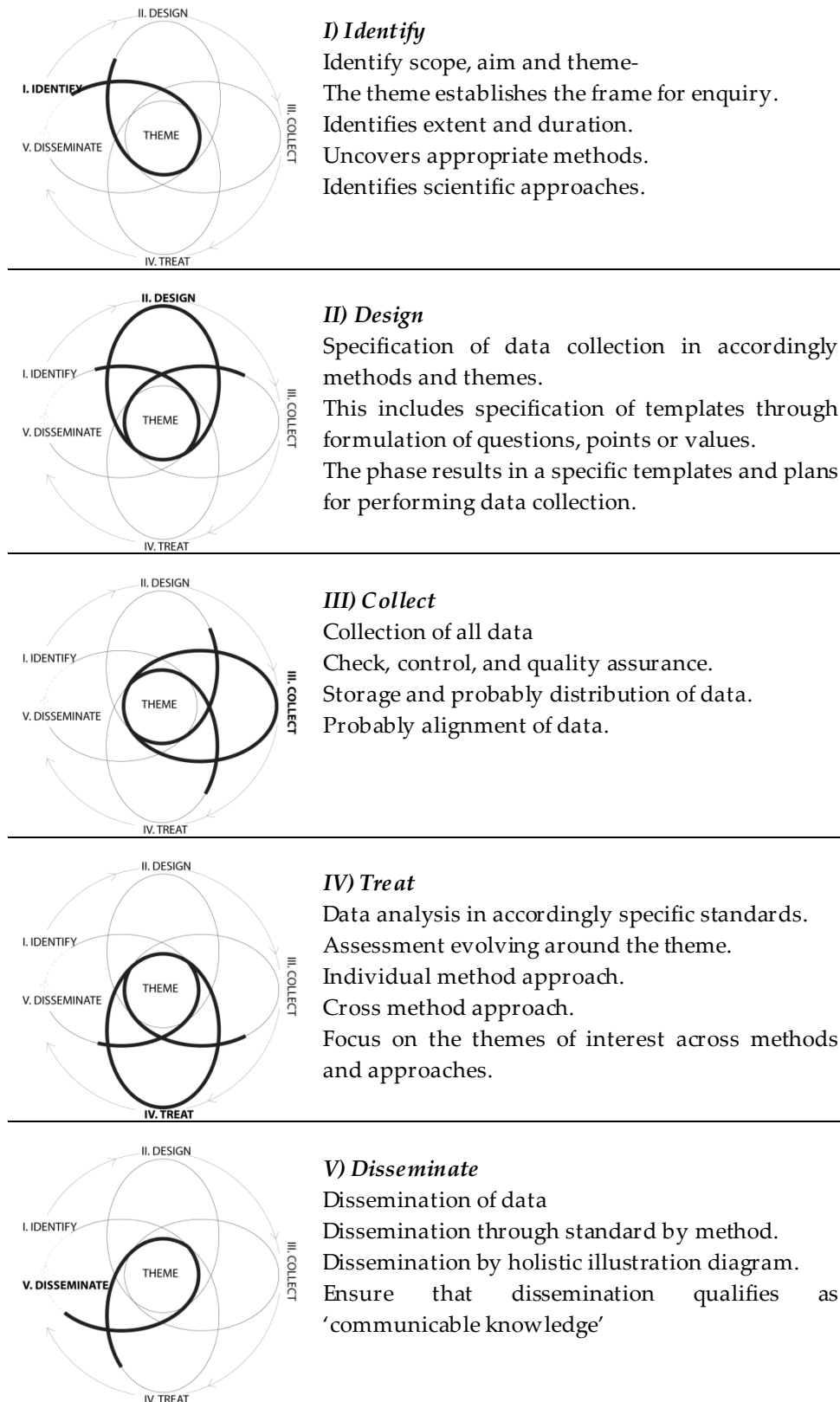
**ill. 4.1.2. Dissemination diagram**

*The illustration showcases an empty template for the dissemination diagram which has the purpose to illustrate four enquiry findings on the same theme in one.*

#### ill. 4.1.3. Model phase steps

The diagram illustrates that this chapter is concerned with the Philosophical World view; one of the cornerstones of the research design.

The Philosophical Worldview is founded on a Pragmatic worldview – while the branches are based on respectively Empirical-Analytical, Positivist, Phenomenological and Hermeneutic worldviews.



## 4.2 Testing the proposed Model of Enquiry

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The proposed Model of Enquiry of Sustainable Homes is put to the test by application to three Model Home 2020 homes and their occupants with the aim of exploring if the model actually provide a more complete illustration of these houses (through the theme of interest) than either of the methods would alone. This holistic and balanced approach is pursued by exploring the identified themes for research respectively *The Human en Centre*, *Perceived Quality in Architecture* and *Perceived Indoor Environment* (see pp. 11-18).

The following pages explore the proposed model for enquiry to exploring the houses through application of the five phases. This process is indented to uncover if and how the proposed methods add to create a more complete understanding of the sustainable homes and to identify where they might and might not be of value to enquiry. Following discussion will reflect on the methodological findings, strengths, weaknesses, opportunities and threats. Finally, the final proposition for a Model for Enquiry of Sustainable Homes is presented.

### **ill. 4.2.1. Sunlighthouse, Austria**

*Sunlighthouse is the Model Home 2020 test house in Austria. It is a new-built single-family house of 304m<sup>2</sup>. The house is built in the mountains outside the capital Vienna, in Pressbaum. The house has a view of the Vienna Mountains, woods and forest. House seen from garden side (south-southwest).*

*Find more information on the house in Part III and a link for the house web-page in Appendix III.*

The three case studies are presented in Part III (see pp. 36-42) and include the German LichtAktiv Haus, the Austrian Sunlighthouse and the French Maison Air et Lumière. Illustrations of the house are showed on these pages (see ill. 4.2.1., 4.2.2., and 4.2.3.).



## Motivation

The motivation for empirical testing of the model is an interest in creating enquiry which is not limited to a certain field of knowledge or science, but is based on theme of interest. Empirical testing will, assumable, enable illumination of which methods are able to and which are not able to provide knowledge that adds to the understanding of the theme. The constructed houses and their occupants provides for possibility to take the research to an empirical and experimental stage. Robinson (1990) comment on the common knowledge division in architecture:

*‘A common tendency in architecture has been to divide “knowledge” into domains associated with particular sub-disciplines. As a consequence, insights derived from research in energy-efficient technologies cannot easily be integrated with insights drawn from aesthetic analyses of exemplar buildings.’*

Thereby, the intent is exactly to integrate knowledge and approaches best appropriate for enquiring and illuminating the aspects of interest.

### **ill. 4.2.2. LichtAktiv Haus, Germany (left)**

*LichtAktiv Haus is the Model Home 2020 in Germany. The house was originally built as a Settlers double-house in 1950ies and lie in an old suburb, Wilhelmsburg outside Hamburg, surrounded by similar houses. The house, now, stand out from the crowd with its new-built, futuristic expression. House seen from garden side (east)*

*Find more information on the house in Part III and a link for the house web-page in Appendix III.*

### **ill. 4.2.3. Maison Air et Lumière, France (right)**

*Maison Air et Lumière is the Model Home 2020 in France. The house is a new-built single-family house situated in the suburb Verrieres-le-Buisson outside Paris overlooking rooftops. House seen from garden side (south-west).*

*Find more information on the house in Part III and a link for the house web-page in Appendix III.*





## 4.3 The human in centre

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### III. 4.3.1. Human and system

*The system in the house is controlled and consulted through monitors placed around the house and through remotes for roof windows.*

*Licht Aktiv Haus, Germany*



### III. 4.3.2. Human and functionalism

*Sustainable functionalism is also about how the house functions in a functional sense, how everyday use and experience is perceived.*

*Sunlight house, Austria.*

*Links to the respective families' blogs can be found in Appendix III.*

*The questionnaire template in its totality is included in Appendix II.*

With the development of technical ability automation is happening on many levels and technology is more or less an integrated part of everyday-life. It is merely impossible to do without Internet access, Smartphone and a load of apps. (Röpke et al., 2010; Janda, 2011) Building automation started out to optimize indoor environmental conditions at work (Wong, Li & Wang, 2005). Now, automation is also moving in at home and thereby a shift in use of homes and the way human beings encounter these is foreseeable (Olesen et al., 2011a). From being merely static floors, walls and roofs with windows and doors that reacts to physical interaction; now these can automatically move, open and close. Mainly, this is based on a programming function, which does not automatically function in sync with user needs but rather intact with pre-programmed patterns. This is a challenging relation as these systems are introduced to comply with users needs. Increased focus on encounters between occupants the automation makes it is central to know about how occupants experience living in and with automated homes. Can feedback from these automation systems increase occupants' awareness of energy use, which is a prerequisite for more energy efficient practices? (Olesen et al., 2013)

### Methodological approach

The system integrated in the Model Home 2020 homes include a range of aspects relating to automation. First, there is a matter of how occupants consult the system, secondly how they operate the system; and finally how they experience automation comply with their needs and expectations. These three aspects all tell something about how the automation system is perceived and what challenges and advantages this add to sustainable functionalism.

Blog research is based on a free for collecting data off the web-site of the individual Model Home 2020. Data are copied off the page, translated into English and categorised accordingly themes of interest. In this case themes circle interaction with automation system. Treatment of data happens through thematic analysis and is disseminated through selected quotes supplied by photos the occupants might have also uploaded to the blog. (Olesen et al. 2013)

Questionnaire, contrarily, is a fixed schematic format with boxed for checking off the question best corresponding to the occupants' perception. Data collection happens through a mail-based system sending out a link to the occupants. This happens seasonally and thereby four times during the test year. Treatment happens as a small scale written statistical analysis, where seasons are compared and compiled in a diagram for visual dissemination.

## Findings on test of the proposed model

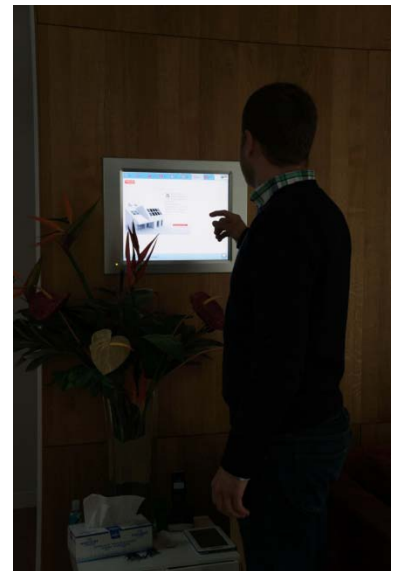
### Blog

Use of the blog is not fixed, but is a free format for the occupants to fill in is both the greatest strength and weakness to the method. A strength, because this provides a platform for the occupants to express anything, whenever. A weakness as it makes it not possible to control frequency, subjects and depth of posts. It is, thus, clear that a natural area of focus is indoor climate, energy and automation and therefore, the occupants often choose to blog about this. The three different families use the blogs in very different ways. The LAH family in the German house post nearly daily smaller observations on the local football team or on specific things or situation in relation to the indoor climate; often supplied with photos. The MAL family in the French house post about once a week, mainly with observations and experiences of indoor climatic related things or the health of the family. From the Austrian house the SLH family post about once a month, but make large posts. They provide rich descriptions of their experiences, and are very thorough, expressed through their room by room descriptions and thorough review of all electrical appliances by measuring stand-by and in-use electricity consumption.

### Questionnaire

Questionnaires, on the other hand, collect data on a determined range of aspects. Every question is specified and a range of answering possibilities is given. The ranges of possible answers are between three and seven with the most defined by five point scales. The questionnaire is sent out by e-mail with a link directly to the test family in the specific house. Questionnaires are sent out four times during the test year in seasonal intervals with approximately three months in-between. The intent with four replies per house is twofold. Firstly, this is to identify if the occupants experience their perception changes during the stay; for instance – is their perception of indoor environment, expression, comfort or automation changing through their stay. The second aspect to the seasonal distribution is to explore if seasonal changes in weather, and thereby for instance dynamics temperatures, daylight, influence occupant experience.

Thereby, a framework for capturing experienced changes is compiled and the data do reflect variability, especially with regards to thermal and air quality means. An unintended aspect is that not the same family member answered every time, creating some variation.



#### III. 4.3.3. Encountering technology

*The monitor screens are controlled by a touch of the hand. It is possible to see current weather conditions and forecast, electricity production by renewable energy sources and consequences of occupant behavior on energy consumption.*

*Maison Air et Lumière, France.*



#### III. 4.3.4. Sustainable functionalism

*Well insulated buildings may cause thick walls. Here, there is a made a virtue of the necessity and the feature is accentuated by integrating large storage spaces in the wall and establishing a lovers-nest-seat instead of a window sill – this can be used for working, naps, guest bed, and much more.*

*Sunlight house, Austria.*



## Findings on occupant encounters

Below, main findings from enquiry in occupant perspectives are:

### Automation

- Technologies at first seem overwhelming but occupants quickly get used to them and following experience them as simple and quickly involve automation in their everyday lives.
- Information from monitors creates understanding of how behaviour affects energy and indoor climate performance and this helps occupants adjust their everyday energy behaviour – experienced as motivating.
- Awareness of possibilities to influence system show increased satisfaction and create positive feelings and experiences.
- Occupants wish to include additional information (e.g. price quote) on monitors and thereby desire knowledge on consequences of behaviour.
- Seasonal variation is experienced as challenging to automation.
- Different strategies to living with automation are illustrated as results of difference in habits, level of knowledge and uses.

### Energy, Indoor climate and Health

- Experience of turning on electric lights later than neighbours and not using light during day time; mainly due to daylight integrated design.
- Designs with much glass area and transparency can be difficult to make completely dark – this is mentioned by two families to affect their sleep.
- Experience that the visualised reduction of energy consumption is related to positive mood.
- Following energy production and being able to compare with energy consumption raises the occupants' awareness and affect practices.
- Occupants experience positive relations between daylight, air quality, natural ventilation and health and that this makes them healthier.
- One family mention they experience reduced signs of asthma and allergies causing reduced use of medicine.
- Comfort challenges on mainly thermal comfort and draught related to both natural and mechanical ventilation in transition periods between summer and winter.

*"For the home atmosphere  
"postcard", this is very nice and the  
light is very beautiful inside. The  
sunrise is even more  
sparkling. Without turning the living  
room chandelier, it sparkles with  
outside light, it's beautiful!  
Today I am sending you pictures:  
pictures are worth more than words!"*

*(Occupant, 14<sup>th</sup> December 2012)*

*Quote from occupants' blog – find  
further information in Appendix III.*

One blog post summons up the research findings in occupants own writing:

*"It's very interesting how quickly we have grown accustomed to the automatics and involved it in our daily lives." (Occupant in LAH, 12<sup>th</sup> June 2012, blog)*

## Concluding remarks

Exploring sustainable functionalism and everyday-life through the eyes and experiences of occupants provides insight into challenges of automated life-form in these three Model Home 2020 homes. Especially, occupants find technology helpful and trust the systems in 'taking care' of their comfort.

The fact that real people live in and test the houses through one entire year (or more) also show that change and variability over day, season and year impacts the experience of living in such a house. Large glass areas in both facades and roofs manages to draw nature closer to the house and integrating its dynamic character more into the occupants awareness. This is reflected in their increased focus on weather and nature, as quotes often express especial appreciation, wonder or worries about the weather.

Sustainability is much more than merely reducing consumption of kWh. Sustainability must infiltrate the design from drawing of the first line to the life unfolded to form the frame for a sustainable life-form. Thereby sustainability is part of everyday functionality, routines, accessibility, interiority, surfaces, maintenance, economics and much more. Economic sustainability is a driver and motivator for sustainable life-form why one central task in architecture is to make gains visible. By raising awareness on occupants everyday behaviour and choices sustainability can occur in successful symbiosis. It makes good sense to integrate and centralise occupant perspectives on life in sustainable homes in enquiry. Occupants are, in the final end, the ones who live in the house and the ones who can judge if the home is in fact sustainable in more than a kWh way.

## Answering the research question

II. *How are everyday encounters with sustainable functionalism perceived by occupants, and what aspects does this bring to an automated, sustainable life-form which is probably a circumstance of the future?*

Occupants in these Model Home 2020 houses manage to rapidly integrate sustainable functionalism in their everyday and use automation systems naturally. The different families reflect different approaches to living in automated homes which support the diversity in energy use in general. Screens inform the occupants about how much energy the technical systems manage to produce and how their behaviour affects consumption of energy. The occupants perceive information from the screens as positive feedback which raises their awareness on energy use and indoor environmental conditions. When the systems produce more than the users consume this creates positive mood.

*"Sun, blue sky and plenty of natural light for breakfast, that makes a good morning! The day can begin and the weekend is coming up... sunny greetings from Wilhelmsburg"*  
(Occupant, 22<sup>nd</sup> March 2013)

*Quote from occupants' blog – find further information in Appendix III.*

## 4.4 Perceived Quality

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### Ill. 4.4.1. Visual walk through

Example from the visual walk through in Licht Aktiv Haus:

‘The lantern staircase room in the old part of the house is a light three stories high space. It has a great staircase that zig zag through the space jointing the three plans. Also, the space is generously lit with natural light from the ten VELUX roof windows.’ (‘Experience Narrative)

There are subjective opinions about what constitutes quality within architecture. These all depend on the eyes that see and the body that perceives. Quality in architecture has always been to creating good architecture; whether named *venustas* (Vitruvius, 1960), *beauty* (Sieverts, 2012) *atmosphere* (Böhme, 1993), it is about creating sensuous perception of spaces through bodily encounter (Pallasmaa, 2005).

Therefore, there is need of more common and tangible ways to capture and convey these so-called in-tangible aspects – elements of perceived quality. In order to capture and document aspects of perceived quality different methods can be applied In-situ. The basic phenomenological approach built on sensuous encounters and the following methods all relate to this. The methods are based on and inspired by existing methods and approaches but developed accordingly need and focus in the respective works. (Olesen & Knudstrup, 2013a; Olesen & Knudstrup, 2013b)

An approach to data collection is inspired by *visual ethnography* (Pink, 2007). The visual, and thereby the camera and the photo, is the essential tool in this approach. (Olesen & Knudstrup, 2013a; Presson & Hazelrigg, 1984; Daniel, 2001)

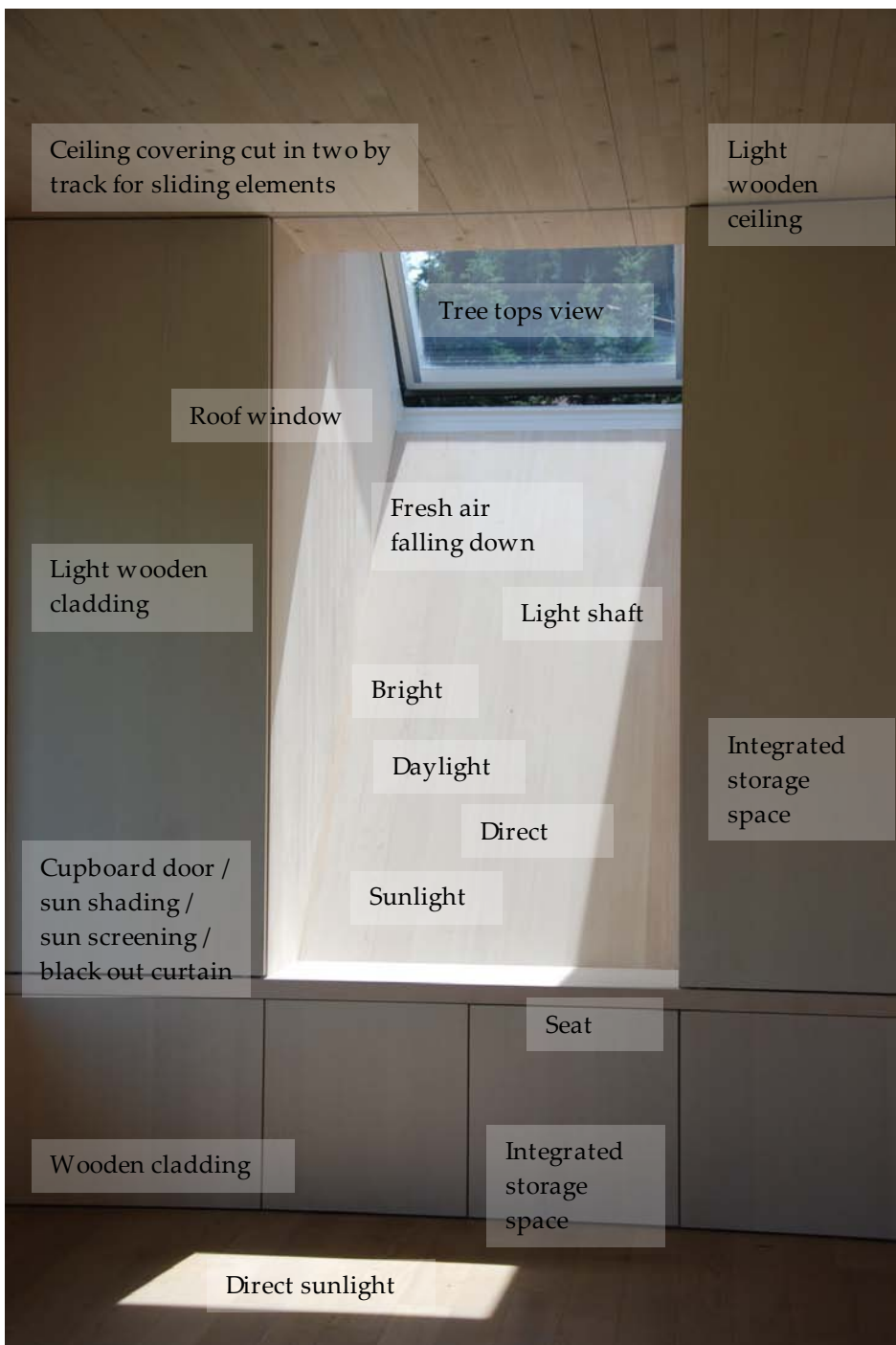
*Time-lapse* studies take photos in fixed intervals of e.g. two minutes; the camera is steady it captures movement of light in space. (Olesen et al., 2011b; Foster, & Oreszczyn, 2001; Baker & Standeven, 1994)

Another approach is the *visual walk through*; a dynamic visual caption of the house – explaining the house room by room – to provide an impression of what the rooms and the flow in the house is like. Rooms are noted at floor plans to provide an overview of situation of spaces, orientation, sun and surroundings.

*Sensation registration/mapping* is an approach in line with the previous one. Here, sensation and notions are noted in the field and following merged with a photo. Thereby a mapping collage of the experienced environment of perceived qualities is compiled providing a visually layered sensation map (see ill. 4.4.2).

A *scheme for collection, treatment and dissemination* of perceived quality in sustainable homes is compiled aiming at forming a more tangible framework for being aware of such elements in enquiry of sustainable buildings. The scheme is enclosed in Appendix IV and can be found in the article (Olesen & Knudstrup, 2013b).

*'Any experience, action, artifact, image or idea is never definitely just one thing but may be redefined differently in different situations, by different individuals and in terms of different discourses. It is impossible to measure the ethnographicness of an image in terms of its form, content or potential as an observational document, visual record or piece of data. Instead, the ethnographicness of any image or representation is contingent on how it is situated, interpreted and used to invoke meanings and knowledge that are of ethnographic interest.'* (Pink, 2007, 23)



#### III. 4.4.2. Sense mapping

The sensation registration/mapping approach collects impressions by senses and connects these with photos afterwards. This is intended to provide a more complete understanding of both sensation and illustration.

The example is from Sunlighthouse, Pressbaum, in the deep roof-wall of the living room provides for a special spatial characteristic with shutters that can close off daylight completely if desired.



Ill. 4.4.3. In-situ studies

Photos from in-situ and field registration trips to the respective Model Home 2020 houses.

## Findings on testing the proposed model

Through enquiry a part of the proposed Model for Enquiry is tested, namely how aspects of perceived quality can be made more easily graspable and thereby possible to collect, treat and disseminate in line with the remaining perspectives explored. A bodily and sensuous approach is pursued.

### Bodily and sensuous approach

The bodily approach to this enquiry makes it possible to apply the sensuous apparatus to data collection (see ill. 4.4.3.). Thereby, the enquiry must happen through a bodily presence in order to activate senses. This, thus, requires time and resources for travelling and possibly disturbing the family. The quality of photos by a professional photographer is very good and show beautiful pictures. Would studying such photos not be enough to spare the costs? Well, if enquiry were merely possibly through images and descriptions only, it would not be possible to capture as air quality, thermal or aural environmental characteristics, tactility of surfaces, smells of materials, dynamics of building elements, feeling a draught from a window when sitting in the couch, discovering the quality of a view through a roof window when lying in bed... These are just some of the elements fundamental to experience home. The approach, thereby, could be described as a sort of architectural ethnography.

### Structuring enquiry through a scheme

The composed scheme is compiled with intention to structure collection, treatment and dissemination of data. The scheme illustrates *Motif* (photo), *Worth* (description) and *Extent* (rating accordingly Likert scale (Likert, 1931)). Application of the scheme shows that the three categories enquiry supports each other well by illustrating each element from different perspectives and thereby the three supplement each other. On the downside, the scheme is not able to control exactly what aspects of the respective elements that are enquired. Application show difference in findings within the same element, for instance within the category *Dynamics*, this is illustrated as respectively dynamic spatial character, dynamic storage solutions and dynamics in the building shell through opening of windows. Thereby, the format does not apply for comparison between houses.

### Perceived quantification

There is also a matter of quantification to the structured approach – an intended feature with an aim of providing for comparison to other types of enquiry. The Likert scale attempts to gently meet quantification of the aspects of perceived quality; however this shows to still be a rather subjective way of rating.

## Findings on enquiry of perceived quality

This section presents findings of enquiries of perceived quality in the three Model Home 2020 houses (Olesen & Knudstrup, 2013b).

### Composition of a scheme for registration

The initial result of the enquiry is identification of elements and composition of the scheme for collection, treatment and dissemination of perceived quality. Identified elements are composed into categories and subcategories. Main categories are: *Perception, Relation, Composition, Surface, Light & Shadow, Variability and Utility*. The scheme in its entirety can be found in Appendix IV.

### Findings on elements of perceived quality

Results are illustrated in ill. 4.4.5 and 4.4.6 (see pp. 59-64) and elaborated below:

*Perception* elements are rated highly, especially in Sunlighthouse and LichtAktiv Haus, while the aural environment in Maison Air et Lumière is rated average.

*Relation* elements have seemingly been highly considered though design which is reflected in ratings. Nature surroundings and long views result in higher ratings than views of city which also bring along the neighbouring looks inside.

*Composition* elements show that all houses are designed highly regarding composition of spaces and integrating roof windows and large facade window areas. Thereby all ceilings are oblique adding to the spaciousness of the houses.

*Surface* elements consist in both natural materials (wood) and more futuristic looking surfaces as solar panels, large reflecting window areas, different colouring and surfaces which automatically move, open and close.

*Light & shadow* elements are of high quality in the houses however a common characteristic are that the houses are excellent at creating bright environments while not that good at creating darkness. Filtering and temporality adds quality!

*Variability* elements depend much on how nature, weather and light are experiences from inside spaces. View has great influence. Choice of material greatly influences perception of durability, patina and aging.

*Utility* elements are found in all houses, thus LichtAktiv Haus and Sunlighthouse display intelligent solutions in their plans, everyday use, interiority element and flexibility, while plan and interiority elements of Maison Air et Lumière are solved rather clumsy and hardly provide space and storage for everyday life.



### Ill. 4.4.3. Light & shadow

Photos from in-situ collection on light and shadow phenomena in respectively LichtAktiv Haus (top), Sunlighthouse (middle) and Maison Air et Lumière (bottom).

### III. 4.4.5. Result of enquiry

The scheme of results displays the findings of enquiry in its most simplified format – at the stage before reducing the findings to numbers. The elements of perceived quality are rated accordingly the Likert scale (1932), by the following specification:

I) Yes, very much

II) To a wide extent

III) Neither/Nor


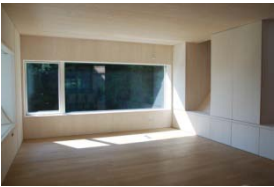



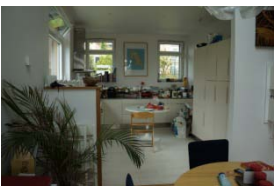
IV) No, not really

V) No, not at all

The scheme is compiled to test if the elements can stand to be reduced in this manner and to prepare these for comparison to other types of enquiry.

	LAH	SLH	MAL
<b>PERCEPTION</b>	<i>Extent</i>	<i>Extent</i>	<i>Extent</i>
<i>Sensuous encounters</i>	<i>Yes, very much</i>	<i>Yes, very much</i>	<i>To a wide extent</i>
<i>Indoor environment</i>	<i>Yes, very much</i>	<i>Yes, very much</i>	<i>To a wide extent</i>
<i>Air quality</i>	<i>Yes, very much</i>	<i>Yes, very much</i>	<i>To a wide extent</i>
<i>Thermal environment</i>	<i>Yes, very much</i>	<i>Yes, very much</i>	<i>Yes, very much</i>
<i>Aural environment</i>	<i>To a wide extent</i>	<i>Yes, very much</i>	<i>Neither/nor</i>
<b>RELATION</b>			
<i>Orientation/ integration</i>	<i>Yes, very much</i>	<i>Yes, very much</i>	<i>To a wide extent</i>
<i>Relation to nature</i>	<i>To a wide extent</i>	<i>Yes, very much</i>	<i>Neither/nor</i>
<i>Connection and transition</i>	<i>Yes, very much</i>	<i>Yes, very much</i>	<i>To a wide extent</i>
<i>Visual privacy</i>	<i>Yes, very much</i>	<i>Yes, very much</i>	<i>To a wide extent</i>
<i>Views</i>	<i>To a wide extent</i>	<i>Yes, very much</i>	<i>Neither/nor</i>
<b>COMPOSITION</b>			
<i>Shape of house /spaces</i>	<i>Yes, very much</i>	<i>Yes, very much</i>	<i>To a wide extent</i>
<i>Impressions and signals</i>	<i>To a wide extent</i>	<i>Yes, very much</i>	<i>Yes, very much</i>
<i>Composition/ proportions</i>	<i>Yes, very much</i>	<i>To a wide extent</i>	<i>To a wide extent</i>
<i>Construction/joints/details</i>	<i>Yes, very much</i>	<i>To a wide extent</i>	<i>To a wide extent</i>
<i>Characteristics</i>	<i>Yes, very much</i>	<i>Yes, very much</i>	<i>Yes, very much</i>
<b>SURFACE</b>			
<i>Membrane expression</i>	<i>To a wide extent</i>	<i>Yes, very much</i>	<i>To a wide extent</i>
<i>Abilities of surfaces</i>	<i>Yes, very much</i>	<i>Yes, very much</i>	<i>Yes, very much</i>
<i>Reflectance / transparency</i>	<i>Neither/nor</i>	<i>To a wide extent</i>	<i>To a wide extent</i>
<i>Tactility of surfaces</i>	<i>To a wide extent</i>	<i>Yes, very much</i>	<i>To a wide extent</i>
<i>Colours of surfaces</i>	<i>To a wide extent</i>	<i>To a wide extent</i>	<i>To a wide extent</i>
<b>LIGHT &amp; SHADOW</b>			
<i>Light and shadow</i>	<i>Yes, very much</i>	<i>To a wide extent</i>	<i>Neither/nor</i>
<i>Brightness and darkness</i>	<i>To a wide extent</i>	<i>Neither/nor</i>	<i>Neither/nor</i>
<i>Anatomy of light</i>	<i>To a wide extent</i>	<i>Yes, very much</i>	<i>To a wide extent</i>
<i>Light space</i>	<i>Yes, very much</i>	<i>Yes, very much</i>	<i>To a wide extent</i>
<i>Filtering and temporality</i>	<i>Yes, very much</i>	<i>To a wide extent</i>	<i>Neither/nor</i>
<b>VARIABILITY</b>			
<i>Perceived variability</i>	<i>Yes, very much</i>	<i>Yes, very much</i>	<i>Neither/nor</i>
<i>Time</i>	<i>Yes, very much</i>	<i>Yes, very much</i>	<i>To a wide extent</i>
<i>Dynamics and movement</i>	<i>Yes, very much</i>	<i>Yes, very much</i>	<i>Yes, very much</i>
<i>Durability</i>	<i>To a wide extent</i>	<i>To a wide extent</i>	<i>Neither/nor</i>
<i>Patina and ageing</i>	<i>Neither/nor</i>	<i>To a wide extent</i>	<i>To a wide extent</i>
<b>UTILITY</b>			
<i>Plan functionality</i>	<i>To a wide extent</i>	<i>To a wide extent</i>	<i>Neither/nor</i>
<i>Everyday use</i>	<i>To a wide extent</i>	<i>To a wide extent</i>	<i>Neither/nor</i>
<i>Automation</i>	<i>Yes, very much</i>	<i>Yes, very much</i>	<i>Yes, very much</i>
<i>Interiority elements</i>	<i>Yes, very much</i>	<i>Yes, very much</i>	<i>Neither/nor</i>
<i>Flexibility and possibilities</i>	<i>To a wide extent</i>	<i>To a wide extent</i>	<i>To a wide extent</i>



Dynamics			
	Motif	Worth	Extent
L A H		The tall staircase space creates an intense dynamic setting with vertical and horizontal moving paths and the plenty roof windows that opens and closes; with internal and external shading moving up and down and shadows moving around painting patterns on walls and floors.	Yes, very much
S L H		The house has many dynamic features. In the living room space movable shutters function as both curtain and cupboard door – across from this a grandlovers-nest seat is integrated in a wall that functions as storage space also. Intelligently integrated solutions.	Yes, very much
M A L		Facade and roof windows function as dynamic elements in the buildings shell – opening or closing changes the shape of the interior space and expression of the outer shape. This dynamic mechanism provides an impression of an organic building that interacts and reacts on its setting.	Yes, very much
Durability			
L A H		The building is put together by a classically shaped gable roof house and the new-built one sided roof added building. Shape language accentuates their different origins and illustrates honesty. The classical versus the more futuristic choice in material reflect different types of durable expression.	Yes, to a wide extent
S L H		The shape of the structure is very particular and moulded to seemingly exactly fit into this place – thereby it is strongly related to the place and nature – and provides an impression that it will change and transform intact with the place – expressing a very local durability.	Yes, to a wide extent
M A L		Durability in the interior arrangement of walls, cupboards and spaces is the frame for the life unfolded over time. Stairs and several floors are possibly not the most durable solutions – these might be challenging to (especially) children or elderly people.	Neither /nor

### III. 4.4.6. Dynamics and Durability

The illustration is from 'Enquiring Perceived Quality in Sustainable Homes: a More Tangible Approach' (Olesen & Knudstrup, 2013b) and is an example of how the scheme can be used for collection, treatment and dissemination of data.

Here, aspects of Variability, namely Dynamics and Durability are showcased.

The scheme shows Motif, Worth and value Extent of each element of Perceived Quality in each of the three enquired houses.



### Sunlighthouse, Austria

Time-lapse studies | 11<sup>th</sup> June 2011



### LichtAktiv Haus, Germany

Time-lapse studies | 16<sup>th</sup> June 2011



### Maison Air et Lumière

Time-lapse studies | 19<sup>th</sup> June 2013



*'The design of a building and its interior space influences its atmosphere and lends a specific character. Together with the features of the room itself the lighting, the materials used, their surfaces, textures and colorings help creating the effect of space.'*

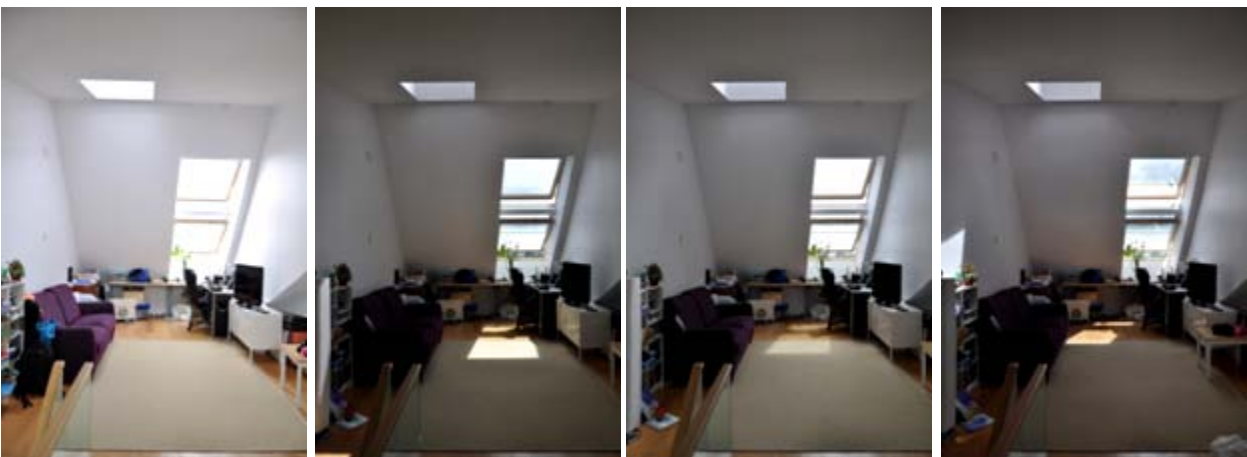
(Pallasmaa, 2007)



*Ill. 4.4.7. Time-lapse studies in Sunlighthouse, Austria*



*Ill. 4.4.8. Time-lapse studies in LichtAktiv Haus, Germany*



*Ill. 4.4.9. Time-lapse studies in Maison Air et Lumière, France*

## Concluding remarks

Perceived qualities in the sustainable built environment should be paid more attention in development and enquiry of sustainable architecture as this puts focus on perceived value for human beings. Perceived quality and values are fundamental elements in good architecture. If these buildings are to be durable and long lasting in use, functionality and day-to-day life architectural quality is central. In that way, elements of perceived quality must be 'measured' and 'weighed' in order to enquire if the building is sustainable in more than a technical sense and can stand to be used without losing its architectural value.

### Variability and dynamics in enquiry

Variability is enquired through elements of respectively perceived quality, Time, Dynamics, Durability and Patina. The approach is able to capture these aspects and reproduce them nicely through photos. Especially photo series based on time lapse approach captures some of the essence of variability (these are reproduced on the previous spread, p. 61-62). Maybe a film format would be even better? Perceived variability is a different type of variability than can be captured through technical enquiry and there is motif to believe that these can supplement each other in explanatory means.

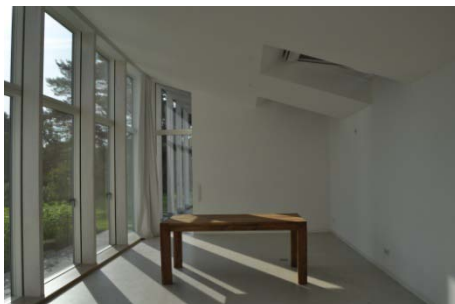
### Schematic approach

With composition of a registration scheme aiming at capturing, assessing and portraying aspects of perceived quality this work suggests a more tangible approach to sustainable architecture. This work could form a platform for further development of an actual tool to registering perceived quality in built environments and provide possibility to implement these aspects in legislation.

*Ill. 4.4.10. Time-lapse studies in  
LichtAktiv Haus, Germany*



*June 15<sup>th</sup> 2011, 07:08 am*



*June 15<sup>th</sup> 2011, 08:02 am*



*June 15<sup>th</sup> 2011, 08:46 am*

## Answering the research question

- III. *Aspects of perceived quality are central to create value for human beings in the built environment of the future, but how can perceived quality in sustainable architecture be registered, analysed, weighed up and conveyed without losing their qualitative nature?*

The work proposes a scheme for registration of perceived quality including aspects of Perception, Relation, Composition, Surface, Light & Shadow, Variability and Utility. Such a schematic format forces a quantification of these very qualitatively loaded elements. However, by pursuing an approach based on both *Motif*, *Worth* and *Extent* these aspects create a space of qualitative interpretation with each element. Thereby, the enquiry is kept three dimensional and not trivialized. Reducing the number of aspect in the scheme of results trivializes the approach too much and the advice is to keep all the aspects in play.

The sensuous and bodily enquiry approach paired with many photos has permitted empathetic descriptions of the various elements of perceived quality in these houses. This provides insights into the spaces and details of the houses that are not possible to imagine based solely on images from the house and neither on technical measurements, blog enquiry or questionnaire surveys.

*'Sustainability is much more than merely technical ability. It is about creating built environments people will care for and thereby create inherent durability through the perceived qualities of everyday life.'* (Olesen & Knudstrup, 2013b)



June 15<sup>th</sup> 2011, 9:42 am



June 15<sup>th</sup> 2011, 10:26 am



June 15<sup>th</sup> 2011, 11:32 am

## 4.5 Perceived Indoor Environment

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### Testing the Model for Enquiry of Sustainable Homes

Awareness of approaching enquiry of buildings in more holistic approaches exists within engineering, social and artistic sciences, yet it is commonly accepted that methods are used individually. Ability to weigh up sustainability is gaining importance, thus, practice need tools to simply assess, portray and communicate required information. The following will test and concretize the proposed Model for Enquiry of Sustainable Homes through Indoor Environmental Aspects through a phase by phase review. (Olesen et al., 2014)

#### I) Identify | Theme, approaches, duration

Based on a pragmatic worldview this model seeks to explore the theme of Perceived Indoor Environment through enquiry from several perspectives. Technical measurements, questionnaire research, occupants' blog research and in-situ research are applied to illuminate indoor environment. Enquiry will be made through one year.

#### II) Design | Design and define data collection approaches

**In-situ research** follows a scheme design that include seven aspects e.g. perception, relation, composition, surface, light & shadow, variability and utility (Olesen & Knudstrup 2013b). **Blog** is a free format where occupants can write about whatever comes to mind (Olesen et al. 2013a). **Questionnaire** includes questions on e.g. level of satisfaction, experience, variation and aspects of being bothered by system carried out seasonally (Olesen et al. 2013a). **Technical measurement** includes continuously logging of temperature (°C), relative humidity (%), CO2 (ppm), lux (lx) and outdoor measurements.

#### III) Collect | Collection and storage procedures

**In-situ** data are collected through field visit to the house for a three day period in June. The designed scheme is used for data collection and further time-lapse studies, visual ethnography, sense registration and visual walk through are used (Olesen & Knudstrup, 2013a; Olesen & Knudstrup, 2013b). **Blog** data are collected right off the blog of each house by the end of the test year and translated into English. **Questionnaire** data are collected seasonally and thereby four times in each house; collection happens through e-mail sending out a link directly to the occupants. **Technical** data are collected through sensors installed in each space in a height of 1.6 meters and are continuously logged. Following data is drawn out in intervals with hourly mean values; all data are quality assured. All data are storage in the designed database.

#### *Data collection templates*

*Templates for data collection can be found in Part VI | Appendix, in their full extent:*

*Appendix I) Technical measurements*

*Appendix II) Questionnaire survey*

*Appendix III) Blog research*

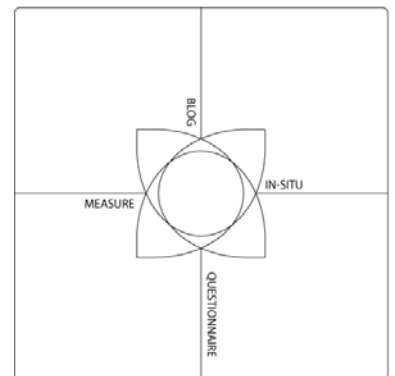
*Appendix IV) In-situ research*

#### IV) Treat | Treat, analyse, assess and rate

In-situ research data are treated through thematic analysis structured by the developed scheme where *Motif*, *Worth* and *Extent* describe each element and provide a three layered rating though illustration, text and rating (see ill. 4.4.6.). Blog posts are treated through thematic analysis and identification of quotes; each can occur several times (Olesen et al., 2013). Questionnaire data are treated accordingly principle of statistical analysis and disseminated through table diagrams displaying seasonal variation (Olesen et al. 2013). Technical data are treated and analysed accordingly given standards and instructions (Olesen et al., 2013a; EN 15251, 2007). (See ill. 4.5.3. for all criteria of enquiry)

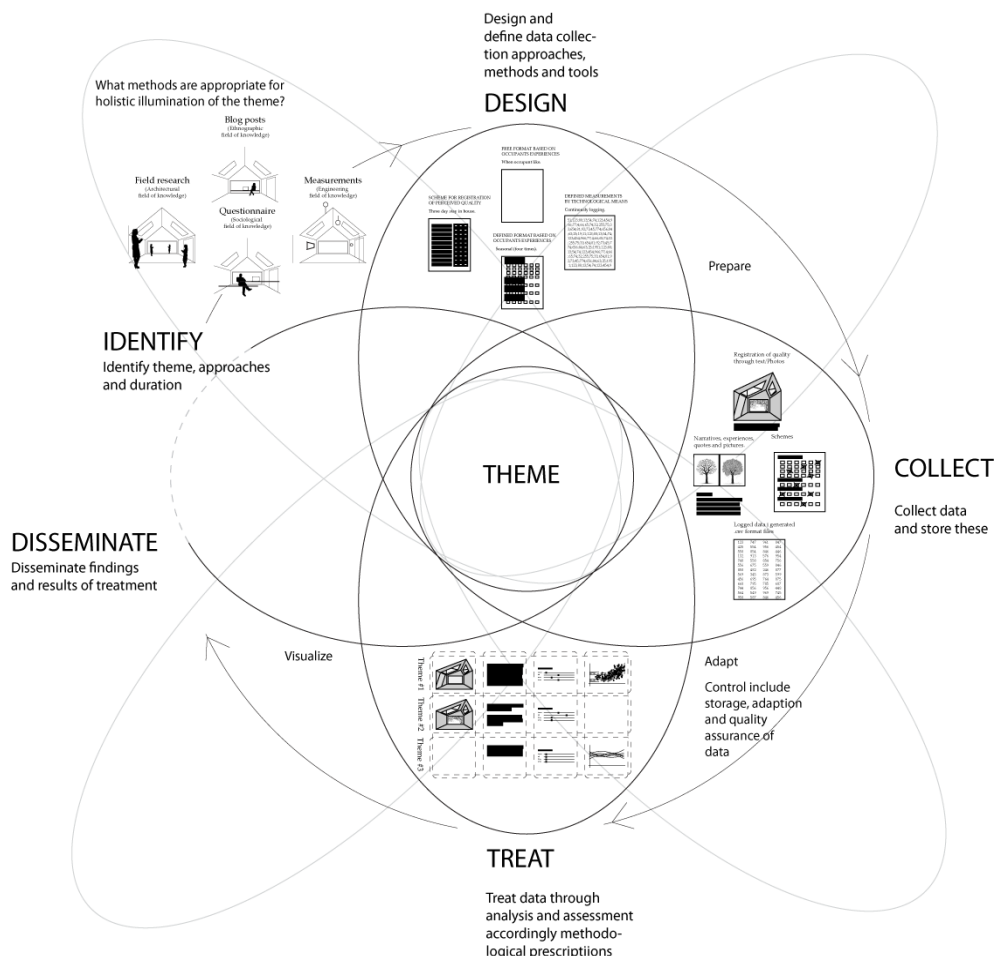
#### V) Disseminate | Disseminate and communicate results

Dissemination of findings is made through a diagram designed for the purpose. The diagram collates an example of each data type representational to the findings and rating achieved though means of individual method is applied. An average rating is stated in the middle. (Olesen et al., 2014)



ill. 4.5.1. Dissemination diagram

The illustration showcases an empty template for the dissemination diagram which has the purpose to illustrate four enquiry findings on the same theme in one.



#### Ill. 4.5.2. Testing the Model

The Model for Enquiry is specified through testing the theme of Perceived Indoor Environment. The diagram illustrate the four methods In-situ research, Blog research, Questionnaire and Technical measurements and their processing through I) Identification, II) Design, III) Collection, IV) Treatment, and V) Dissemination.

(Olesen et al., 2014)

Please find an enlarged version of the illustration on page 87.

#### Following spread (67-68)

#### Ill. 4.5.3. Criteria for Enquiry

The table contains data collection, treatment/rating and dissemination criteria on the respective four methods and four categories of indoor environment including Thermal environment, Air quality, Daylight & View and Acoustics.

(Olesen et al., 2014)



	IN-SITU RESEARCH	BLOG
D A Y L I G H T & V I E W	<p><b>Data collection methods:</b> In-situ (three day visit) <i>Scheme of Perceived Quality in Sustainable Homes, visual ethnography, visual walk through, sense registration</i></p> <p><b>Light &amp; Shadow elements:</b> Light and shadow, Brightness and darkness, Light space, Anatomy of light, Filtering and temporality <b>View elements:</b> Orientation/ integration, Relation to nature, Connection/transition, Visual privacy, Views</p> <p><b>Rating</b> in compliance with <i>Scheme of Perceived Quality in Sustainable Homes</i> (Olesen &amp; Knudstrup, 2013b) I) Yes, very much; II) To a wide extent; III) Neither/Nor; IV) No, not really; V) No, not at all.</p>	<p><b>Data collection methods:</b> Blog (when occupant like)</p> <p><b>Phrases with content on:</b> brightness; availability of light; direct sunlight; diffuse light; distribution; direction; orientation; weather; size; shape; materials; colour; texture; furnishing; integrated solutions; functions; flexibility; frames; screening; view; visible sky; visible objects and landscape located further away; transmittance; green and nature; near views; visual privacy; orientation; framing; adjustability; control.</p> <p><b>Rating</b> based on thematic analysis in compliance with defined five point scale where V is lowest rating and I is highest rating.</p>
T H E R M A L E N V I R O N...	<p><b>Data collection methods:</b> In-situ (three day visit) <i>Scheme of Perceived Quality in Sustainable Homes, visual ethnography, visual walk through, sense registration</i></p> <p><b>Thermal environment elements:</b> (thermal comfort, variation, fluctuation, shading, draught, materials, heat capacity, spatial organisation, direct solar gains, airing, adjustability, control, system interface)</p> <p><b>Rating</b> in compliance with <i>Scheme of Perceived Quality in Sustainable Homes</i> (Olesen &amp; Knudstrup, 2013b) I) Yes, very much; II) To a wide extent; III) Neither/Nor; IV) No, not really; V) No, not at all.</p>	<p><b>Data collection methods:</b> Blog (when occupant like)</p> <p><b>Phrases with content on:</b> temperature, warmth, warmer, warm, cold, colder, pleasant, thermometer, windows, comfortable, draught and hot.</p> <p><b>Rating</b> based on thematic analysis in compliance with defined five point scale where V is lowest rating and I is highest rating.</p>
A I R  Q U A L I T Y	<p><b>Data collection methods:</b> In-situ (three day visit) <i>Scheme of Perceived Quality in Sustainable Homes, visual ethnography, visual walk through, sense registration</i></p> <p><b>Air quality elements:</b> (fresh air feeling, dampness, mould, materials, window sizes, adjustment, interface, control)</p> <p><b>Rating</b> in compliance with <i>Scheme of Perceived Quality in Sustainable Homes</i> (Olesen &amp; Knudstrup, 2013b) I) Yes, very much; II) To a wide extent; III) Neither/Nor; IV) No, not really; V) No, not at all.</p>	<p><b>Data collection methods:</b> Blog (when occupant like)</p> <p><b>Phrases with content on:</b> fresh air, pleasant, draught, ventilation, windows, pleasant air, opening, stuffy, smell, air quality, mechanical ventilation, breeze, automatic, sick, ill, allergies, irritation and clean.</p> <p><b>Rating</b> based on thematic analysis in compliance with defined five point scale where V is lowest rating and I is highest rating.</p>
A C O U S T I C S	<p><b>Data collection methods:</b> In-situ (three day visit) <i>Scheme of Perceived Quality in Sustainable Homes, visual ethnography, visual walk through, sense registration</i></p> <p><b>Acoustics elements:</b> Sound, noise, opening, windows, outside, hear, listen, raindrops, automatic, others, screening, systems noise</p> <p><b>Rating</b> in compliance with <i>Scheme of Perceived Quality in Sustainable Homes</i> (Olesen &amp; Knudstrup, 2013b) I) Yes, very much; II) To a wide extent; III) Neither/Nor; IV) No, not really; V) No, not at all.</p>	<p><b>Data collection methods:</b> Blog (when occupant like)</p> <p>Phrases with content on: Sound, noise, opening, windows, outside, hear, listen, raindrops, automatic, other occupants, screening and systems noises.</p> <p><b>Rating</b> based on thematic analysis in compliance with defined five point scale where V is lowest rating and I is highest rating.</p>



QUESTIONNAIRE	TECHNICAL MEASUREMENTS
<p><b>Data collection methods:</b> Questionnaire (seasonal)</p> <p><b>Main questions:</b> State how satisfied or dissatisfied you are with the temperature conditions? How have you experienced the temperature conditions in the following rooms during the last couple of weeks? Have you experienced varying temperature? How often do you experience being bothered by varying temperatures in the house? How often do you experience being bothered by experiencing downdraughts from the windows?</p> <p>Rating based on thematic analyses presented through graphs following a five-point Likert scale (1932) here V is lowest rating and I is highest rating.</p>	<p><b>Data collection methods:</b> Technical measurement (continous logging)</p> <p>Daylight level measured in lux, fixed ceiling sensors. Simulation in e.g. VELUX Daylight Visualizer.</p> <p><b>Rating</b> in compliance with AH Specification (Gillet et al., 2013) expressed through graphs, and EN 15251 (2007) and five-point scale: I) DF &gt; 5%; II) DF &gt; 3%; III) DF &gt; 2%; IV) DF &gt; 1%; V ≤ 1% on average. Direct sunlight availability for minimum one of the main habitable rooms sunlight provision should be able between autumn and spring equinox: At least: I) 10% ; II) 7.5%; III) 5%; IV) 2.5%; V) &lt; 2.5% ... of probable sunlight hours.</p>
<p><b>Data collection methods:</b> Questionnaire (seasonal)</p> <p><b>Main questions:</b> State how satisfied or dissatisfied you are with the temperature conditions? How have you experienced the temperature conditions in the following rooms during the last couple of weeks? Have you experience varying temperature conditions? How often do you experience being bothered by varying temperatures in the house? How often do you experience being bothered experiencing downdraughts from the windows?</p> <p>Rating based on thematic analyses presented through graphs following a five-point Likert scale (1932) here V is lowest rating and I is highest rating.</p>	<p><b>Data collection methods:</b> Technical measurement (continous logging)</p> <p>Sensors installed in all spaces on walls placed 1.6 m above floorout of direct sunlight and draught.</p> <p><b>Rating</b> in accordance with EN15251 (2006:27). Illustrated as graphs with measured indoor air temperature as function of measured exponentially-weighted running mean outdoor temperature graphs includes four categories defined by three ranges, where <math>\Theta^i</math> is limit value of indoor operative temperature and <math>\Theta^{rm}</math> is running mean outdoor temperature. I: <math>\Theta_{i\max} = 0.33\Theta^{rm} + 18.8 + 2</math> and <math>\Theta_{i\min} = 0.33\Theta^{rm} + 18.8 - 2</math> II: <math>\Theta_{i\max} = 0.33\Theta^{rm} + 18.8 + 3</math> and <math>\Theta_{i\min} = 0.33\Theta^{rm} + 18.8 - 3</math> III: <math>\Theta_{i\max} = 0.33\Theta^{rm} + 18.8 + 4</math> and <math>\Theta_{i\min} = 0.33\Theta^{rm} + 18.8 - 4</math></p>
<p><b>Data collection methods:</b> Questionnaire (seasonal)</p> <p><b>Main questions:</b> How have you experienced the air quality in the house during the last couple of weeks? Have you experienced any problems the air quality being...? What do you usually do if you want to improve air quality? How often do you experience being bothered experiencing downdraughts from windows?</p> <p>Rating based on thematic analyses presented through graphs following a five-point Likert scale (1932) here V is lowest rating and I is highest rating.</p>	<p><b>Data collection methods:</b> Technical measurement (continous logging)</p> <p>Sensors installed in all spaces on walls placed 1.6 m above floorout of direct sunlight and draught.</p> <p>Rating in accordance with EN15251 (2006:36-38). CO<sub>2</sub> level: I) 350 ppm; II) 500 ppm; III) 800 ppm; IV) &lt; 800 ppm ... above outdoor level. Relative humidity: I) 50% - 30%; II) 50-60% or 25-30 %; III) 60-70% or 20-25% IV) &gt; 70% &lt; 20%</p>
<p><b>Data collection methods:</b> Questionnaire (seasonal)</p> <p><b>Main questions:</b> State how satisfied or dissatisfied you are with sound and acoustics conditions in the house? Are you at all bothered by the sound of the systems?</p> <p>Rating based on thematic analyses presented through graphs following a five-point Likert scale (1932) here V is lowest rating and I is highest rating.</p>	<p><b>Data collection methods:</b> Technical measurement (continous logging)</p> <p>ZEB (Olesen et al., 2013b) identifies advise criteria for design values for sound levels from installations in residential buildings: Living room typical range 25-40 dB(A) (default design value 32 dB(A)); Bedroomtypical range 20-35 dB(A)(default design value 32 dB(A))</p> <p>Spot measurements can also be carried out on e.g. reverb, impact; airborne; installation or trafic sound. (DS490:2007)</p>

## Findings on testing the proposed model

*An aim of testing the proposed model of enquiry firstly in parts and secondly in its entire form with all methods applied is to explore if the methods proposed actually help forming a more complete understanding of the matter than either of the methods would alone. So, do they and what is learned from testing?*

### **In-situ research**

- Provides a deeper insight into architectural and sensuous aspects establishing a valuable frame for understanding all other data types.
- Show elements of perceived quality that add value to life - everyday.
- Creates a frame for understanding what does/does not function.

### **Blog**

- Provides a very selective illustration of the circumstances reflecting occupants' mood and experiences at the time; snapshot of experience.
- Provides insight into occupants' life, annoyance and joy in the houses.
- A weakness that the character of the data is so uncertain.
- Data help decode questionnaire answers, technical data and quality.

### **Questionnaire**

- Appropriate for creating a basic understanding of how it is experienced living in the house, the *how*; but lack ability to describe the *why*.
- Valuable for understanding blog and technical measurement data.

### **Technical measurements**

- Valuable tool to comprehend technical ability and reflect other data.
- Should be considered in line with the other methods as not as lead.

### **Aspects of time and variability**

- The duration of the enquiry is strength to the model as it illuminated aspects of time, dynamics and variability in such homes. This is found to resemble the actual sustainability to a much wider extent than the methods are able to do alone. An aspects often lacking in enquiry.

### **General considerations**

- Not all elements are possible to illuminate though all methods; thus, two or three methods do also add to comprehending the element.
- The testing show that the methods work well in a parallel process where not one is the lead method; this provides a skewed perspective.
- Both cases of coherence and contradiction between methods provide knowledge adding to comprehend the sustainability of a house.

## Findings on enquiry

*The following outline findings of enquiry of perceived indoor environments of the three inhabited Model Home 2020 houses. (Olesen et al., 2014)*

### **General findings on thermal environment**

Thermal environment in the Model Home 2020 houses are of general high quality and are rated well through all methods, namely blogs express a high degree of satisfaction. (Olesen et al., 2014)

### **General findings on air quality**

Findings on air quality are of varied character. Occupant perspectives by blog and questionnaire generally express high degree of satisfaction with air quality and sensation of fresh air, through blogs air quality is accentuated as a central quality (all) and contributing to good health (MAL); while measurements rate the air quality in LAH *too high* generally across the year due to high peaks during summer mainly in bedroom and library; in-situ research finds air quality in MAL stuffy. (Olesen et al., 2014)

### **General findings on daylight and view**

The general level of daylight in the house is high, an aspect greatly appreciated by occupants. Focus on daylight optimization and design has to some degree lead to lack of possibility to creating darkness in the houses. (Olesen et al., 2014)

The houses present different examples of view. LichtAktiv house has an intimate and natural view; Sunlighthouse has both an intimate view to the nearby treetops and a magnificent view of the woods and mountain landscape; while Maison Air et Lumière has a view of the city and rooftops. All occupants state that view is important to them. (Olesen et al., 2014)

### **General findings on acoustics**

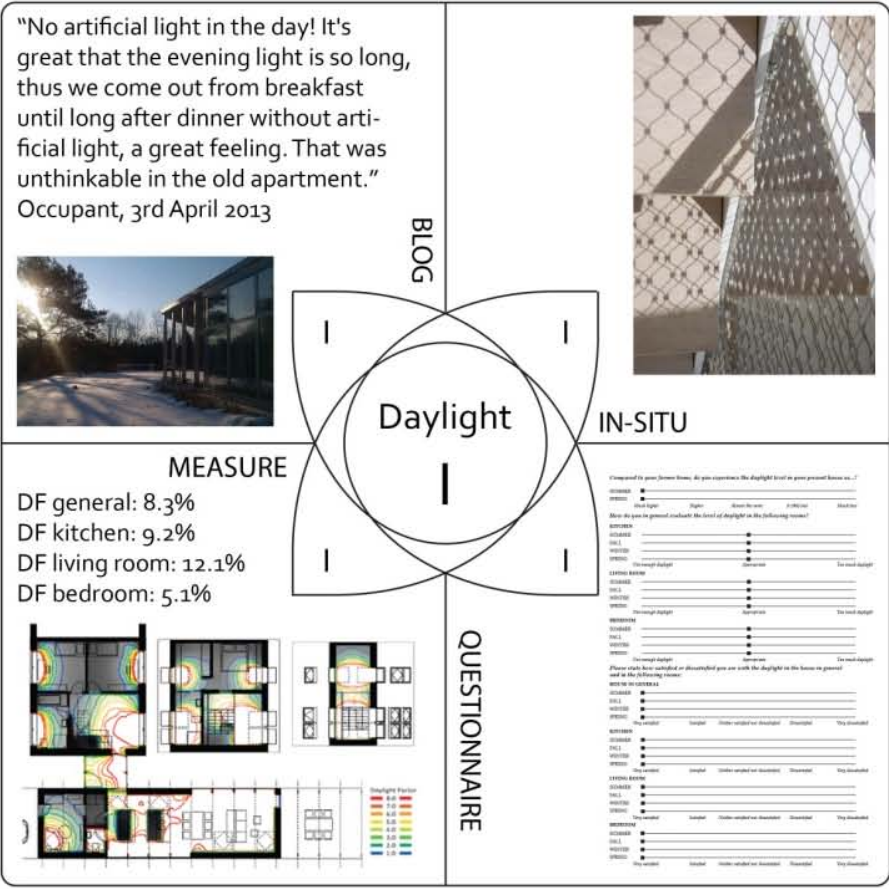
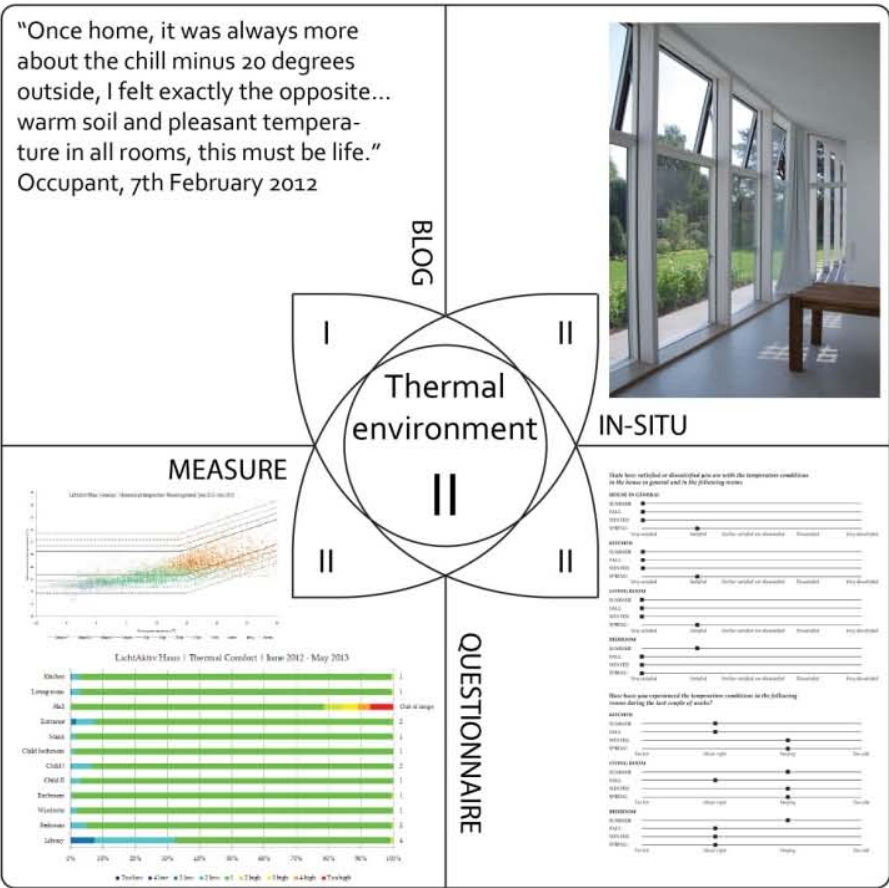
It is not possible to create adequate illustration of aspects acoustics in the homes, why these are not illustrated thorough the rose. However, occupant experiences enquired through blogs and questionnaire find that aspects of aural environment are significantly influence sensation of comfort and a pleasurable perceived indoor environment in the houses. (Olesen et al., 2014)

## Disseminated through diagram

On the following pages results of enquiry through the model are disseminated through the developed diagram (see p. 47). Elaboration on these results can be found in (Olesen et al., 2014); thus here, only the diagrams are presented aiming at illustrating the methodological use of the developed dissemination diagram.

LichtAktiv Haus

Wilhelmsburg, Hamburg, Germany

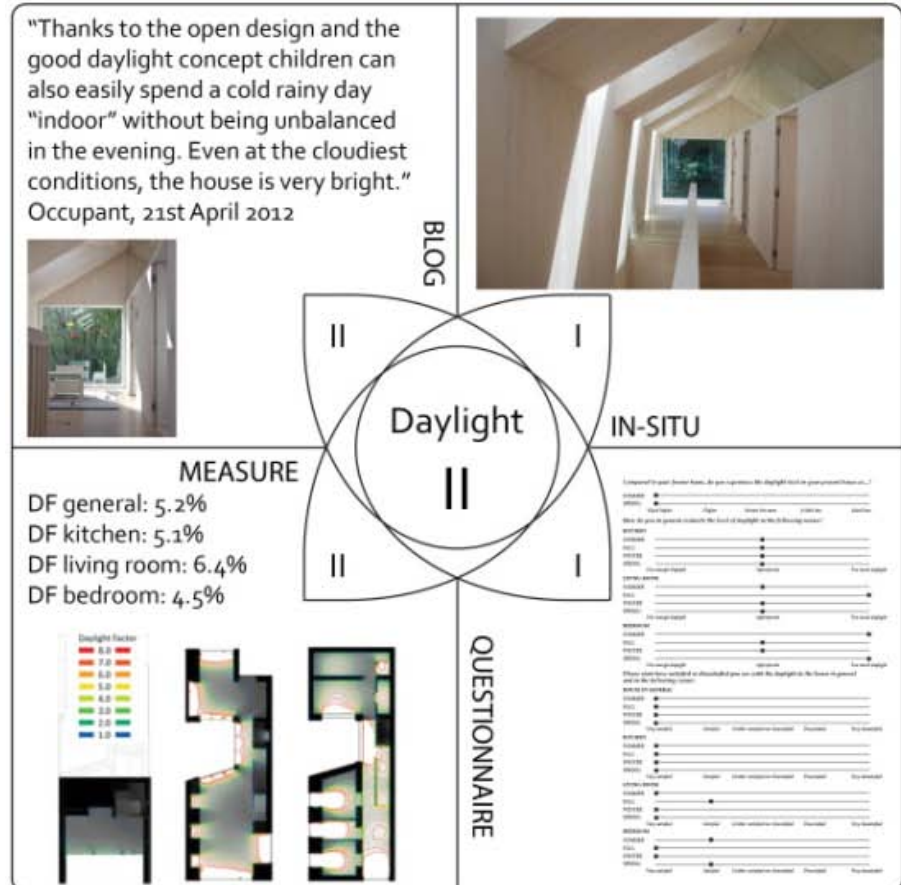
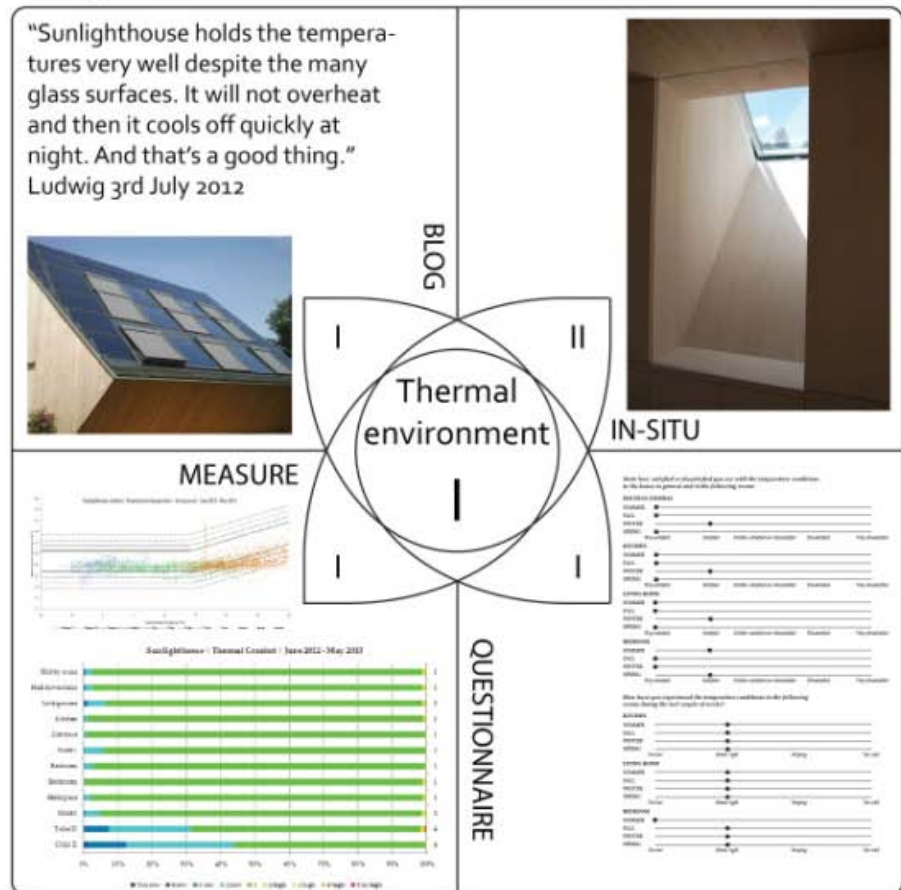






# Sunlighthouse

Presbaum, Vienna, Austria

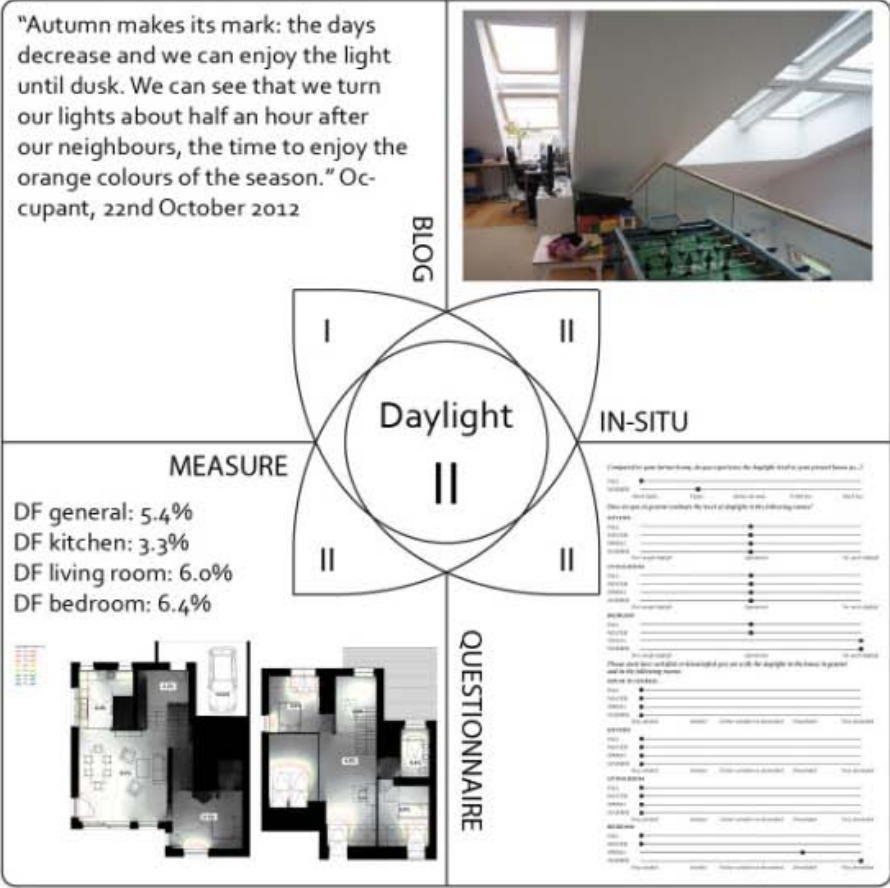
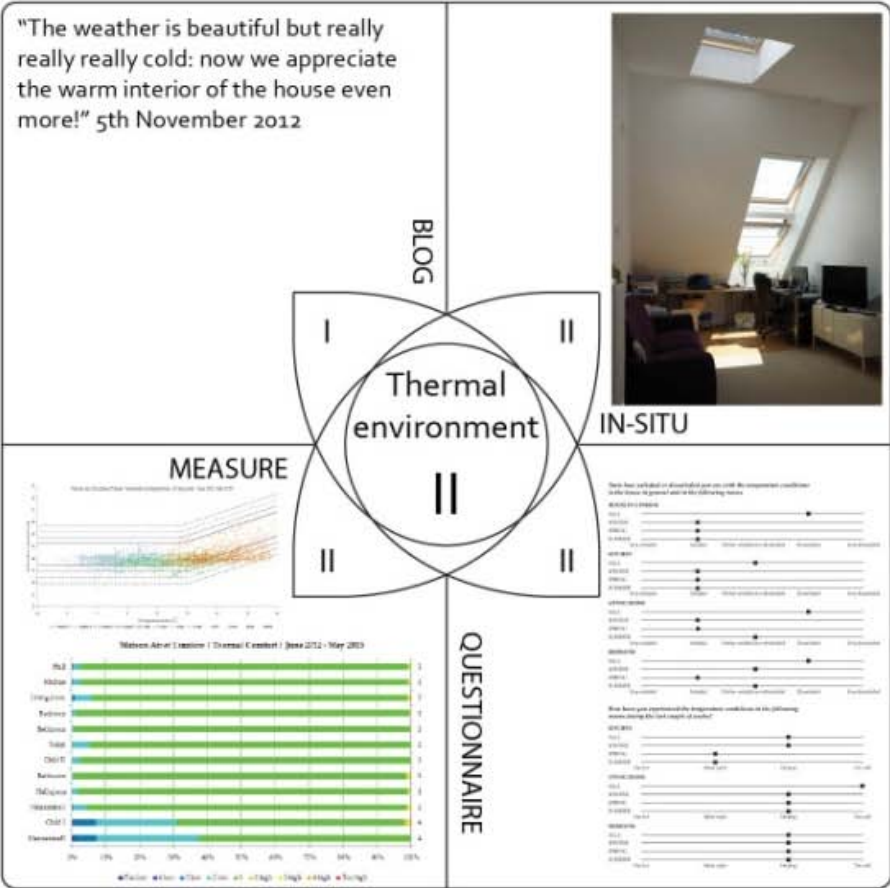


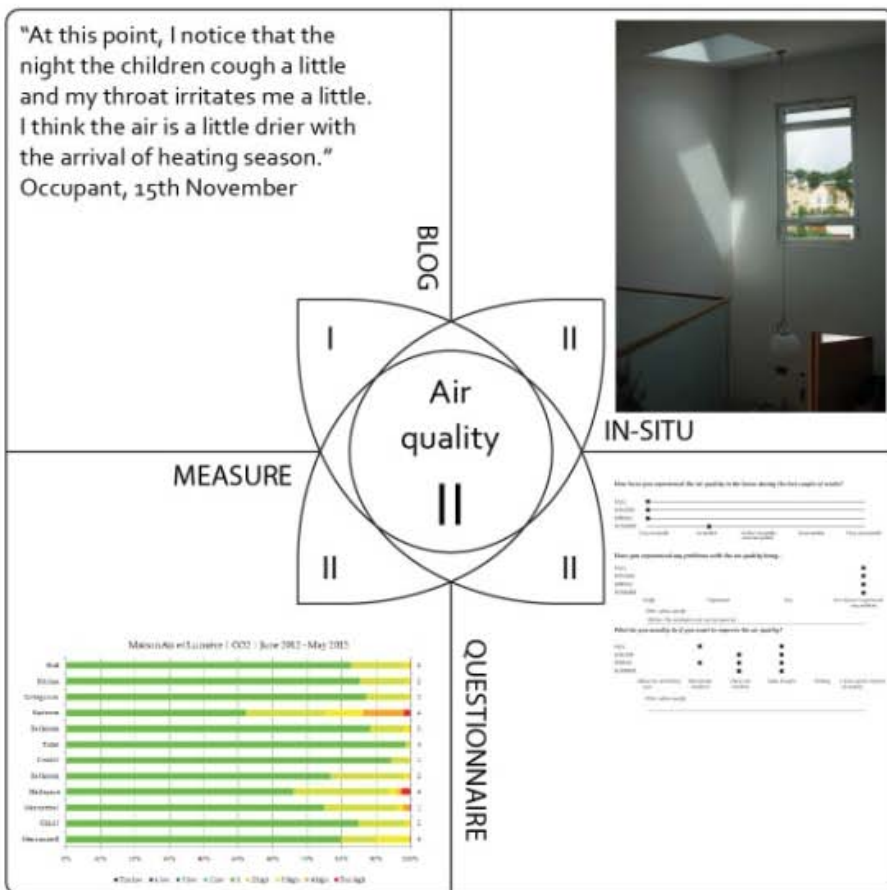




Maison Air et Lumière

Verrieres-le-Buisson, Paris, France



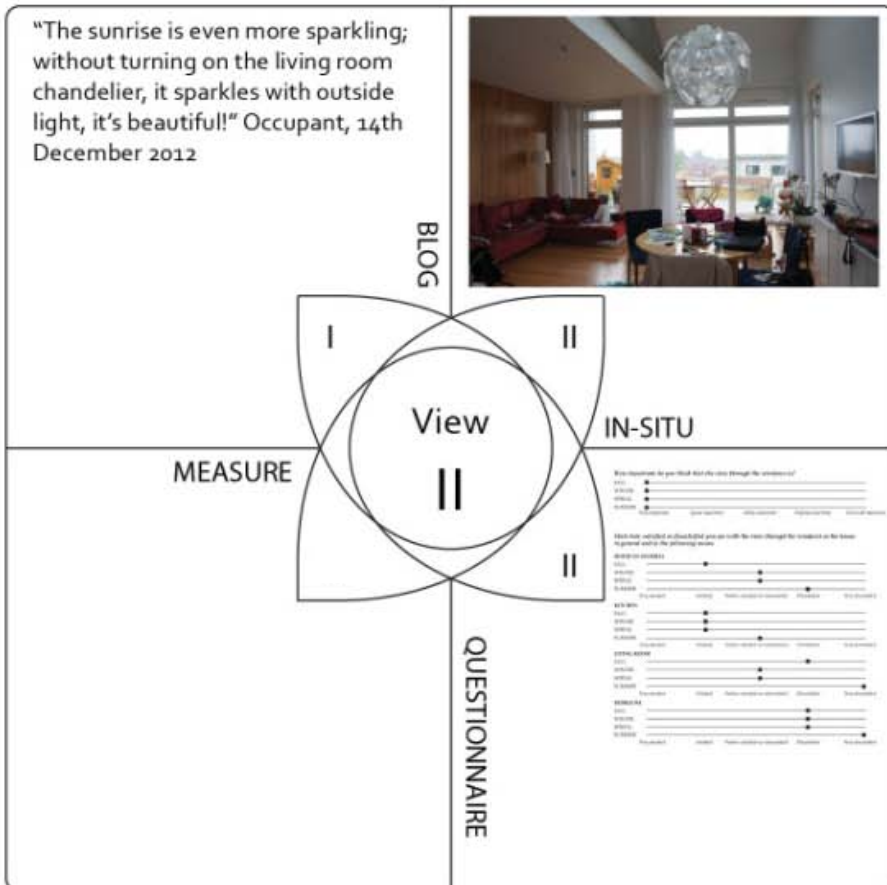


Spread (75-76)

### Ill. 4.5.4. Dissemination diagram – Maison Air et Lumière, France

Dissemination diagram here filled in with findings and ratings on respectively Thermal environment, Air quality, Daylight and View.

(From Olesen et al., 2014)



## Concluding remarks

In general indoor environments in the three sustainable Model Home 2020 houses enquired are of high quality. Especially thermal comfort and daylight designs are scoring high in the diverse enquiry approaches. Air quality is theme of more variable character, and seemingly occupants experience air quality as better than measurements rate them to be. Aspects of aural environments are hardly collected and not measured at all. However, occupant experiences enquired through blogs and questionnaire survey point to aspects of the aural environment are strongly contributing to creating a sensation of comfort and a pleasurable perceived indoor environment in automated homes.

This enquiry format presents a synthesized illustration of perceived indoor environment and thereby illustrates a holistic and balanced enquiry of the sustainability of inhabited Model Home 2020 homes.

## Answering the research question

- IV. *How can indoor environment in sustainable homes be enquired through respectively occupant perspectives, perceptual quality and technical ability; so the approaches supplement each other and establish a more complete illustration of the sustainability unfolded?*

The mixed methods approach pursued through this work enables coupling four perspectives on perceived indoor environment; namely architect perspectives through field research enquiry, occupant perspectives through respectively blog and questionnaire approach and a technical perspective through measurements. Enquiries through the four approaches are carried out in a concurrent triangulation setup, enabling illumination through four perspectives simultaneously. Thereby, the approaches are found to supplement each other and establish a holistic illustration of aspects. Technical measurements create precise quantitative illustration of the indoor environmental conditions and can tell something general about the level of comfort performed by the house. Technical measurements, however, lack ability to elaborate if the level of comfort established is in fact experienced as comfortable for the actual occupants. Here, questionnaire and blog methods have their eligibility. These are both appropriate for collecting occupant perspectives. The strength of the questionnaire is a certainty on what information is collected. Precise question define what is desired to know, and even though it is not possible to make sure that the occupants interpret the questions as intended, they are stoutly pointed in the right direction. Also, it is defined when the schemes are sent out so it is manageable when data are desired. Elements of perceived quality are not merely icing on the cake but enquired on the same level as the remaining approaches contributing to establishing a holistic illustration of the sustainability unfolded and generating a more complete picture than either methods would alone.

## 4.6 Discussing the Model of Enquiry

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The previous chapters have identified the theoretical and methodological foundation for the research and further unfolded design, collection, treatment and dissemination through the model of enquiry of sustainable homes. This process of unfolding has aimed at exploring the main research question:

- I. *How can a model for enquiry of sustainable homes based on a mixed methods approach include occupant perspectives, perceptual quality and technical ability; so the approaches supplement each other and establish a more complete illustration of the sustainability unfolded?*

The following chapter will discuss and elaborate the findings from the enquiries with an aim of exploring potentials and limitation to the proposed model and thereby answer and reflect on this research question.

The discussion relates to mainly the empirical application of the model and discusses how and why the methods proposed are relevant to establish more holistic and balanced approaches to enquiry of sustainable homes.

Discussion will focus on the following themes and questions:

**I) Methodological approach**

*Do the applied methods supplement each other?*

**II) The model in relation to research themes**

*How does the model answer to the research themes of interest and with what focus?*

**III) Added value and potential**

*How does the model add value to the process of enquiry of sustainable homes and where doesn't it add value?*

**IV) Generalization and validity**

*Through the research, the model has been based and tested on Model Home 2020, but is it valid to other types of sustainable housing and thereby generally applicable?*

## Methodological approach

*Do the applied methods supplement each other?*

The holistic and balanced aspect of the research is cultivated through a mixed methods approach to compiling the Model for Enquiry of Sustainable Homes. This intends to underline importance of pursuing several perspectives in enquiry to meet the holistic and balanced nature of sustainable architecture in the future. Thereby, not only one method or approach is preferred, but the preferable is to apply the methods best appropriate for enquiring the specific problem or theme of interest and thereby to figure out what methods are able to provide answers to a certain topic through a pragmatic approach. So, what did this pragmatic empirical enquiry with application of several methods show and do the methods applied for testing supplement each other?

### Strengths, weaknesses, opportunities and threats

Illustration 4.6.1. (see p. 81) show how aspects of indoor environment paired with methods for enquiry rate these. Thereby, the figure on the one hand illustrates what methods are appropriate for providing an answer to the different themes of indoor environment. For instance, *thermal comfort* is rated by all methods while the aspect of *surface temperatures* is only rateable by in-situ research in the houses. Secondly, the illustration provides information on how methods rate the different elements of indoor environment. Ill. 4.6.1. shows that all four methods are able to rate the element of thermal comfort: LichtAktiv Haus (the column to the left) is rated II by respectively *In-situ enquiry*, *Questionnaire* and *Technical measurements*; while Blog rates the element I. For Sunlighthouse (the middle column) *In-situ research* rates II while the remaining methods rate it I. Maison Air et Lumière (column to the right) rating vary more and *In-situ research* rates it II, *Blog* rates it I, *Questionnaire* rates it III and *Technical measurements* rates it II. Here I is the best rating and five is worst.

*Next page (81)*

### Ill. 4.6.1. Scheme of enquiry

*The scheme illustrates how each method rate the respective elements of respectively thermal environment, air quality, daylight and view and acoustics. Also, the scheme show what methods are able to provide rating to, and thereby knowledge on, the respective elements.*

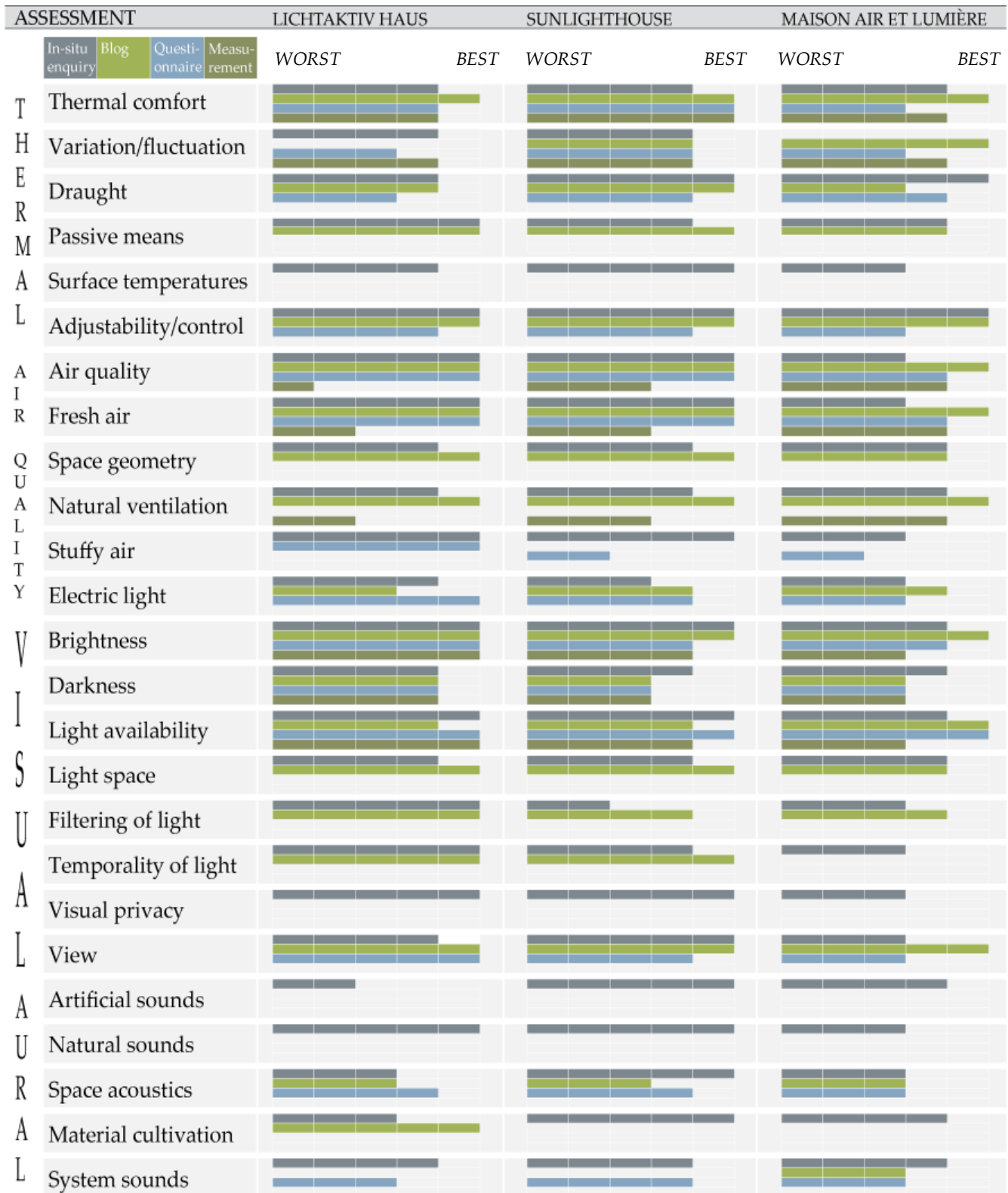
*(From Olesen et al., 2014)*

So, what are generally the strengths and weaknesses to the methods applied for enquiry though this model?

### In-situ research (see. Ill. 4.6.2.)

In-situ field research is able to provide answers to many of the elements defined. This is due to its format where researcher is present in the field and much information is layered in the bodily memory and is possible to transform to describe a certain element. Simultaneously, the in-situ approach is very much based on sensuous means creating an inherent bias as two researchers may not collect the exact same information to the defined elements. This aspect, can also





**III. 4.6.1. Assessment diagram.** The scheme illustrates what methods are able to enquire and rate elements of indoor environment and additionally states how these methods rate the elements. The diagram is based on a rating principle of category I till V and in the scheme the best rating is to the right (rating I) while the worst rating is to the left (V). (From Olesen et al., 2014)

be considered a strength of the approach as this represents a variability of human perception. Thereby, such a rating as the one made though ill. 4.6.1. is difficult to make, as it is not completely transparent what a specific rating actually stand for. To enquiry the validity of the approach, an empirical study where several researchers carry out registration by the scheme format in the same location, could provide occasion for exploring general applicability.

#### **Blog research** (see. Ill. 4.6.3.)

Variation/fluctuation (ill. 4.6.1.) is rated by all methods in SLH and MAL, while not by blog method in LAH. This is due to the character of the blog research, where the format is laid out freely for the occupants to write about whatever they feel like. This approach has proven to be a disadvantage in this situation, as it is not possible to ensure that desired elements are measured. Some of the rated aspects are merely based on one blog statements. The approach thereby is based on a snapshot of a situation; which is likely not representational to the year of experiences in the house. This point to, that a deduction/quantification of the parameters to a level like this is not preferable; simply as the design and collection of data was not geared for this. On the other hand, the non-structure and non-quantifiable of the blog format provides opportunity to collect data on aspects which might not have been regarded importance during the study. This for instance goes for findings on perceived relations between air quality and health of the family. The format is found as a suitable substitute for the previously explored diary approach. Respectively blogs and data provide different insights in occupant experiences, thus, illuminate each other and thereby manage to create a more complete illustration, of some aspects. A more streamlined guidance for blog posts and more frequent but shorter questionnaire could possibly provide for more coherence in the data types and could further help semi-automating the data treatment process. Within the field of sustainable buildings blogging provides a new opportunity to capture user experiences. The format is based on occupants own interest, time and effort and might possibly reduce workload of researchers significantly. Still the format is difficult to compare to more quantified types of data.

#### **Questionnaire** (see. Ill. 4.6.4.)

Questionnaire enquiry is commonly used in research in the built environment to explore occupant opinions on a given subject – often indoor environmental aspects. The special thing about applying questionnaire survey to this enquiry is the number of enquiries. All in all twelve times (three houses and four seasons) is the questionnaire completed. In a classical sense this does not apply for statistical analysis which is commonly the way to analyse quantities of questionnaire data. Thereby, the questionnaire can be seen in a slightly different light through this study as it focuses on exploring occupant experiences as a

counterpart to blogs. The two methods can thereby create a frame for validation for each other – and possibly for the other methods as well. The questionnaire is designed and applied with focus on seasonal data collection. This approach has proven valuable to establish an illustration of dynamics in this life-form and how these affect occupant experiences. Especially fall and spring periods indicate challenges to the systems in the eyes of the occupants. The format is always a bit uncertain due to the inability to know exactly how occupants interpret the questions and answering possibilities which makes it difficult to interpret what lie behind the reply. The format is better suit for a larger sample of houses – thus, it is a helpful tool in interpreting other data types.

#### III. 4.6.2. In-situ research SWOT

*Strengths, Weaknesses, Opportunity and Threats to the In-situ research part of the Model for Enquiry of Sustainable Homes.*

In-situ	
<b>STRENGTHS</b> <ul style="list-style-type: none"> <li>- Based on sensuous means</li> <li>- Roots experiences in the sensuous and bodily apparatus and thereby its available</li> <li>- Illustrative and communicable</li> </ul>	<b>WEAKNESSES</b> <ul style="list-style-type: none"> <li>- Based on sensuous means</li> <li>- Lack transparency in rating</li> <li>- Expensive if travelling far</li> <li>- Only one visit was possible</li> </ul>
<b>OPPORTUNITY</b> <ul style="list-style-type: none"> <li>- Carry out seasonally</li> <li>- Can be used across building types</li> <li>- Several research making same studies</li> </ul>	<b>THREATS</b> <ul style="list-style-type: none"> <li>- Admittance to location</li> <li>- Validity of the format</li> <li>- Comparability to other enquiry methods</li> </ul>

#### III. 4.6.3. Blog research SWOT

*Strengths, Weaknesses, Opportunity and Threats to the In-situ research part of the Model for Enquiry of Sustainable Homes.*

Blog	
<b>STRENGTHS</b> <ul style="list-style-type: none"> <li>- Free format, unlimited subjects can provide interesting information the research would not have considered</li> <li>- Ongoing collection</li> <li>- Rich posts/quotes with great narratives</li> </ul>	<b>WEAKNESSES</b> <ul style="list-style-type: none"> <li>- Free format makes unsure what data are collected</li> <li>- Some aspects only have one post</li> <li>- Indifferent posts irrelevant to theme</li> <li>- Much information is lost in rating</li> </ul>
<b>OPPORTUNITY</b> <ul style="list-style-type: none"> <li>- A format that can be used anywhere, anytime in the way best appropriate</li> <li>- Capture photos of every day in houses without on occupants' conditions</li> <li>- Establish valuable insights in every day</li> </ul>	<b>THREATS</b> <ul style="list-style-type: none"> <li>- Dependent on occupant mood/if they use blog or not</li> <li>- Based on snapshots – decrease validity</li> </ul>

### Technical measurements (see. Ill. 4.6.5.)

Technical measurements are enquired at a basic level though these enquiry exercises as much research and knowledge on the technical level already exists. Thus, strengths and weaknesses appear in relation to interaction with the remaining methods. The accuracy in the technical approach is striking, and is both experienced as strength and weakness. The level of detail can show a very detailed picture of the building – but is such accuracy necessary in relation to the Model for Enquiry? The approach also only provides a quantitative answer (a what) and never a qualitative answer (the why)

Questionnaire	
<b>STRENGTHS</b> <ul style="list-style-type: none"><li>- Fixed format, you know what you get</li><li>- Seasonal (ability to capture change)</li><li>- Occupants decide when</li><li>- In the home – bodily presence help strengthen memory.</li></ul>	<b>WEAKNESSES</b> <ul style="list-style-type: none"><li>- Not possible to elaborate answers</li><li>- Might be difficult to decode intentions behind the crosses.</li><li>- Not sure if the answering possibilities are understood in the same way by everyone.</li></ul>
<b>OPPORTUNITY</b> <ul style="list-style-type: none"><li>- Validate other data types</li><li>- More often</li><li>- Fill in when blog post (cross validate)</li></ul>	<b>THREATS</b> <ul style="list-style-type: none"><li>- Misinterpretation of questions</li><li>- Only collecting the what not the why</li><li>- Better suitable for larger quantity of houses</li></ul>

### Ill. 4.6.4. Questionnaire SWOT

*Strengths, Weaknesses, Opportunity and Threats to the In-situ research part of the Model for Enquiry of Sustainable Homes.*

Technical measurements	
<b>STRENGTHS</b> <ul style="list-style-type: none"><li>- Technical accurate</li><li>- Level of detail in data (1 min possible)</li><li>- Tell a thorough technical story</li></ul>	<b>WEAKNESSES</b> <ul style="list-style-type: none"><li>- Level of detail in data (1 min possible)</li><li>- Answers the what, not the why</li><li>- Some loggings are difficult to translate to knowledge</li></ul>
<b>OPPORTUNITY</b> <ul style="list-style-type: none"><li>- Apply to more themes (e.g. acoustics)</li><li>- Spot measurements e.g. in relation to round of questionnaire</li><li>- Level of detail in data (1 min possible)</li></ul>	<b>THREATS</b> <ul style="list-style-type: none"><li>- Dependent on proper equipment</li><li>- Drowns in quantity of data</li><li>- Broken equipment/poor equipment</li><li>- Level of detail in data (1 min possible)</li></ul>

### Ill. 4.6.5. Technical measurement SWOT

*Strengths, Weaknesses, Opportunity and Threats to the In-situ research part of the Model for Enquiry of Sustainable Homes.*

## The model in relation to themes for research

*How does the model answer to the research themes of interest and with what focus?*

### Holistic and balanced approaches

Often, enquiry includes several professionals who are each experts on their domain of knowledge (Hansen, 2010; Brunsgaard, 2011). This model of enquiry is developed through an approach where the same researcher performs all enquiries. This might not be the procedure pursued in practice where a team of specialists may be required to cover all aspects. By the same researcher carrying out all explorations, template designs, data collection, treatments and analysis and dissemination the pragmatic worldview is supported. The thereby approach test if the inherent specialist barriers are in fact broken down through this process or if the barriers remain. The experience is that barriers are more broken down compared to processes where a handful of specialists are involved; thereby immense insight into that data material across adds to the depth and quality of the findings. A down side is then, that only one person sits on this knowledge and aspects of dissemination thereby becomes even more important. This is supported by the development of the dissemination diagram; which is intended to support communicating the holistic and balanced story of the sustainability of the theme of home in focus. This research thereby contributes to the field of enquiry in sustainable architecture by pointing towards a more holistic and balanced approach where theme and focus of enquiry is superior to specific knowledge fields or professions.

### Occupant perspectives

Occupant perspectives are explored through respectively questionnaire and blog survey. Thereby an area of tension for unfolding occupant perspective is established; on the one hand a controllable and directly quantifiable approach through questionnaires and on the other hand a free approach based on blogs. This tension provides a frame for exploring their posts and crosses a bit deeper and especially point to problematic aspects concerning diversity and variability. This work thereby contributes to focusing on variability in the built environment as a key to understanding how sustainable functionalism and life-form is and how designs can be created to support these dynamics?

### Perceived quality

Architectural traditions have developed through centuries with strong inherent understanding for qualities based on cultural, scenic, spatial and social realms through an art of refining combination of materials, space, light, function and landscape. Architects are challenged and committed to make qualities in the surrounding environments noticeable so they can be perceived by users and

thereby add to the quality of the building. There are subjective opinions about what constitutes quality within architecture or the art of buildings, and they all depend on the eyes that see. In architecture there is not a simple quantitative answer to a building design and contrary to natural sciences this is not the objective. Architecture proposes individual interpretation with the subject as a vital parameter and architecture is created in the encounter between human being and building structure. Besides being research objectives the Model Home 2020 projects are suggestion of future sustainable architecture. The buildings are designed with eye for new expression of shape, integration of known and new types of materials, elements of technology and large size windows and areas. The model attempts to make some of the elements of perceived quality more approachable through compiling a scheme. Effects of new and known means of housing architecture are thereby made visible.

This in-situ approach to exploring the qualitative layers of the model for enquiry are interesting to reflect against technical means and occupants' perception and opinions of what reflects quality in this type of architecture. The model contributes to the field by making this relation between different perspectives and models evident.

### Perceived indoor environment

The research theme of perceived indoor environment is so to say the main theme for testing the model and all aspects possible are applied in this enquiry. The model is able to provide answers to a range of the selected themes by more than one method; thus, a range is only answered to by means of in-situ research. Through testing the model, it becomes evident that more general themes, such as thermal comfort and daylight are easier to develop knowledge on than more specific aspects. Thereby, the model also reflects that some elements stem from technical fields of knowledge while other stem from in-situ scheme.

### Added value and potential

*How does the model add value to the process of enquiry of sustainable homes and where doesn't it add value?*

Applying the Model of Enquiry to the three houses, among other things, shed light on where the model can add value and potential to the area of enquiry of sustainable homes. POE's are commonly used and increasingly applied to both old housing and new-built. The potential in the new-built environments, or a through renovation such as is the case in LichaAktiv Haus, are immense for integrating technological equipment and sensors in the construction and



thereby visually integrated in spaces. And even more technical measurements could be applied to log presence of number of persons in a space or frequency of interacting with the automation systems. Thereby, there is a great potential to illuminate user behaviour on a wider level; where possibly an addition of technical measured knowledge could add to occupants own experiences of life in sustainable homes to learn from occupants variability patterns.

An aspect uncovered through application of the model for enquiry is influence of variability. State-of-the-Art studies indicated that variability is a tendency to be aware of and the enquiries through this research supports this. Aspects of variability add value to the enquiries as these aspects are able to illustrate change in these environments. Also, the enquiries point to a sensibility related to aspects of variability and this is expressed in several aspects through the encounters with the three homes. Variability is of central value through the enquiries as all measurements are of variability of some sort. Technical measurements register variability in temperatures, CO<sub>2</sub> levels, relative humidity and light levels

Creation of stability, standards and status quo are all concerned with looking at the fixed solution of effect. By enquiring variability and dynamics in sustainable homes it would probably be possible to illustrate the actual sustainability of a home in a more complete way. Thereby, the model for enquiry contributes with a new focal point of variability across methodologies that could well add value to the development and enquiry of sustainable architecture of the future.

## Generalization and validity

*Through the research, the model is developed and tested on Model Home 2020, but is it valid to other types of sustainable housing and thereby generally applicable and valid?*

### **Generalization**

The enquired Model Home 2020 houses are State-of-the-Art examples of sustainable single-family housing based on net zero energy intentions. The houses are initiated, designed and constructed with ambitious intentions and curiosity by carefully selected architects, engineers, craftsmen, materials and products (VELUX 2010; Sloth 2010). The houses have been giving special attention and care through all phases, something which is reflected in their architecture and general high quality. Therefore, it is relevant to discuss, if the developed Model for Enquiry can be used in general or if it is only suitable for high-end homes?

The basic elements of the model as specified through means of indoor environment are common to all buildings. Thermal environment, air quality, daylight, view and acoustics are basic premises for establishing good indoor environments. This applies for buildings whether small row-housing from the 1950ies or large office buildings from the 2010s. The model thereby represents an approach to enquiring which all types of buildings can fall under and in addition a shortlist of what should be included through these enquiries.

Another aspect of generalization is rating of elements. The scale approach and technical standard means that all elements through the enquiry are rated following a five point scale. This approach makes it possible to put the rating alongside each other and judge for instance what method is better at rating an aspect or through which method the better rating is obtained. This approach to rating outcome of all methods and aspects create a frame for comparison to anything which can be quantified into the same five point rating scale. Thus, this approach is dicey, as this point towards quantification of all aspects. This is in fact the exact development this work attempts to counter. Still, it was discovered, that the deduction to numbers is a common language and can be considered a valid starting point for comparison. A next step could be attempting turning the rating around to merely base ratings on purely qualitative means. To view sustainability through qualitative perspectives only could be an interesting challenge to the strictly defined quantitative approaches in search for new perspectives and methodology.

### **Validity**

The methods applied through the present enquiry originally belong to different fields of knowledge and are inherently based on different scientific worldviews. Discussing validity of the model can thereby be approached from various perspectives. One perspective could be, that the different fields of knowledge applied to the work through would cause for them to overrule one another. Natural scientists might claim that social and anthropological methods are loose stories; while anthropologists might accuse natural-scientific methods for merely displaying some statistical aspects with no real use full knowledge for understanding what is actually going on. Here, the basic pragmatic worldview is appropriate to look to, as it focuses on using what makes the most sense at the time, disregarding divided fields of knowledge. This is the belief behind the model and the aspect which is underlined through the thematic focus the model revolves around. Thereby, the model is considered valid across knowledge fields and valid for constituting a more complete illustration of sustainability.

## 4.7 Presentation of the final Model of Enquiry

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*Through the previous pages steps of developing the Model for Enquiry have been tested, explored and enquired. The efforts result, here, in a presentation of the final suggestion for a Model for Enquiry of Sustainable Homes. See ill. 4.7.1 ill. 4.7.2. and ill. 4.7.3.*

### **I) Identify**

- Identify theme and subjects of interest
- Review and identify what approaches are available to illuminate the theme
- Determine duration of the enquiry and possible challenges

### **II) Design**

- Design templates for all methods (see PART VI, Appendix I-IV)
- Define data collection approaches/units (see ill. 4.7.3.(a-b))
- Prepare for collection (book trips, test equipment, create databases)

### **III) Collect**

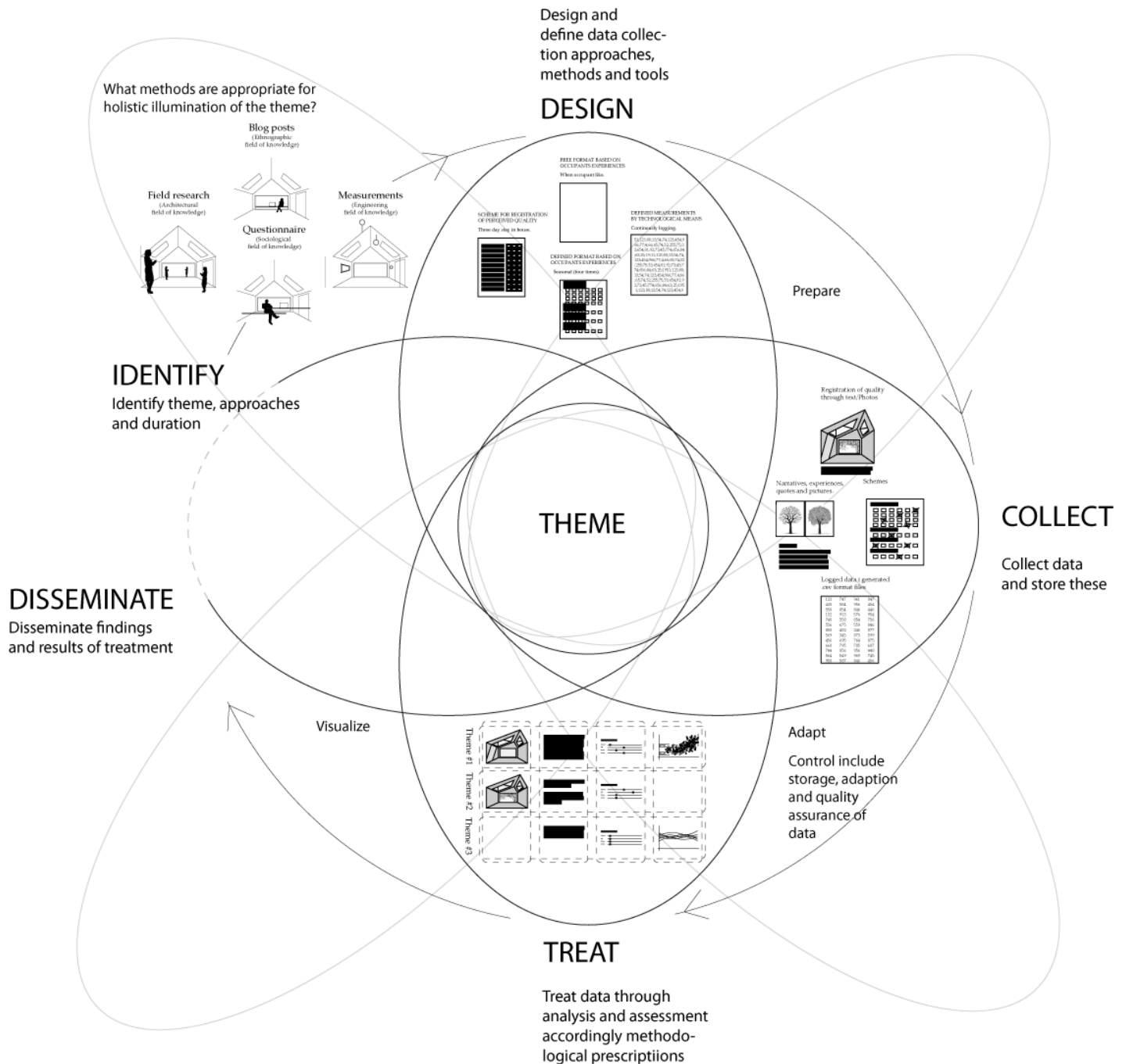
- Collect data (off Internet, travel, databases, and other...)
- Check data and quality assure (see ill. 4.7.3.(a-b))
- Storage in the prepared database

### **IV) Treat**

- Thematic focus though treatment based on individual methods approaches to compile mixed methods findings
- Rating of findings in compliance with criteria (see ill. 4.7.3.(a-b))

### **V) Disseminate**

- Prepare diagrams, tables, illustration on individual methods
- Compile dissemination diagram containing findings and rating from each knowledge field in the designed dissemination diagram (see ill. 4.7.2.)
- Communicate findings

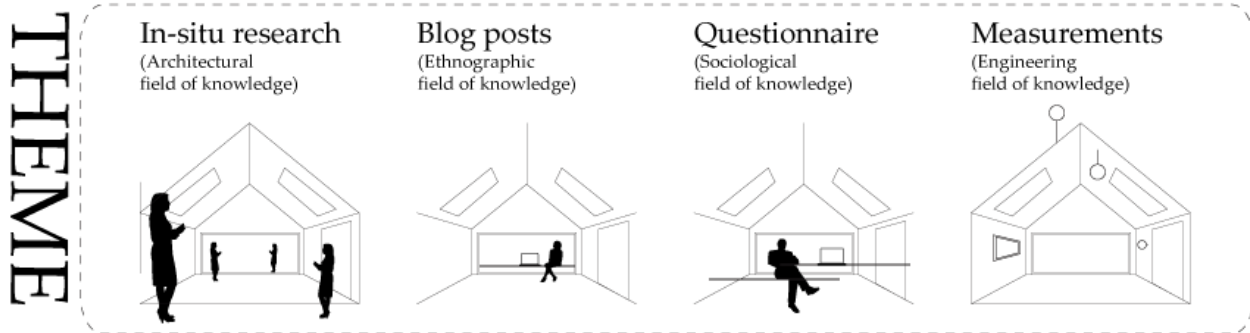


### III. 4.7.1. The Model for Enquiry of Sustainable Homes through Aspects of Indoor Environment.

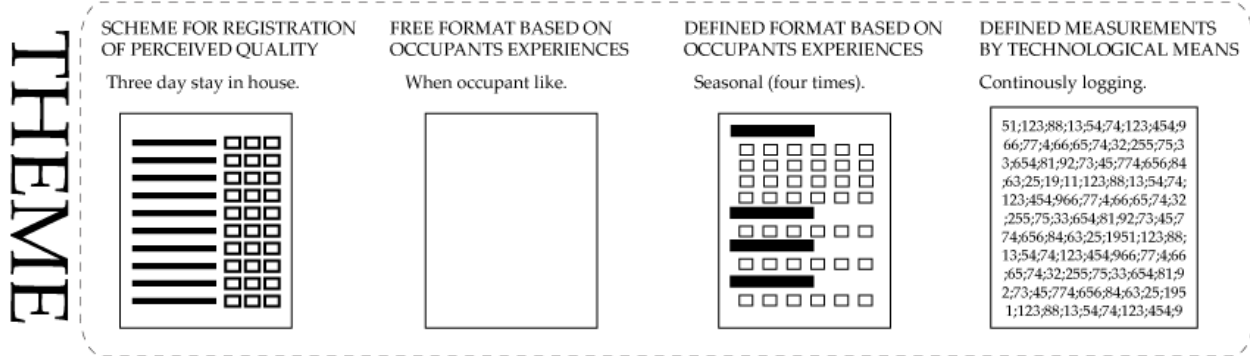
Pictograms are integrated in the model to represent the different methods through the different steps. Pictograms are elaborated on the following pages in ill. 4.7.2.

(From Olesen et al., 2014)

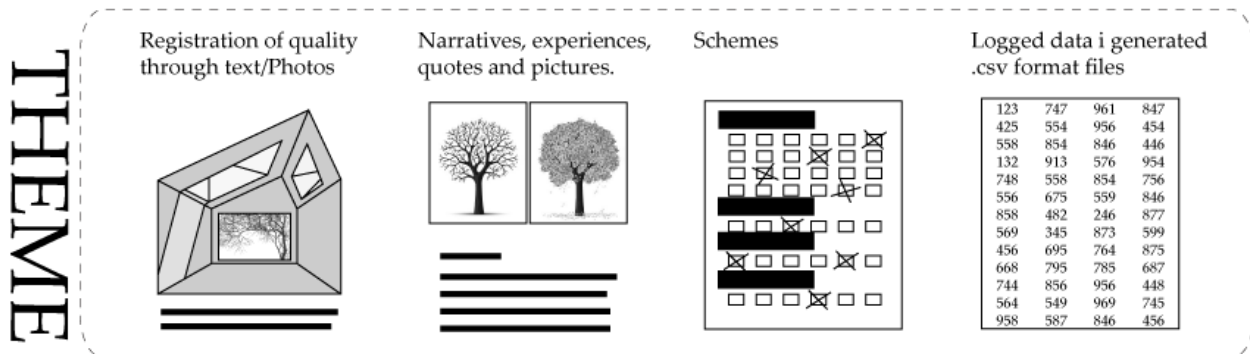
## I) IDENTIFY



## II) DESIGN



## III) COLLECT



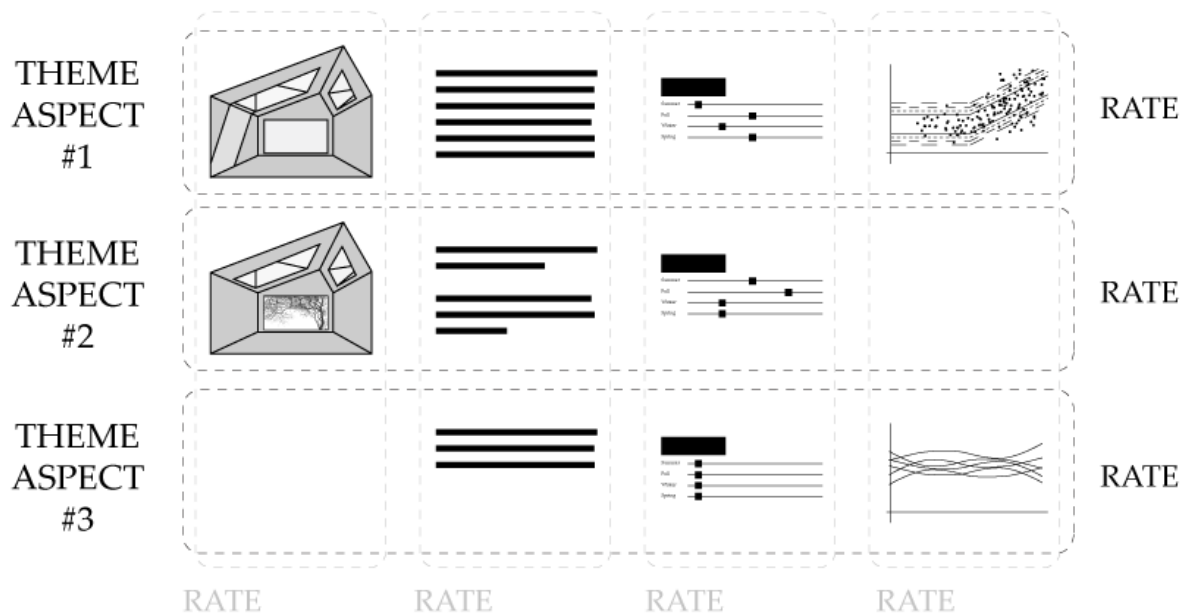
### III. 4.7.2. Phase diagram – phase by phase illustration by pictograms

The illustration shows the five steps of the Model for Enquiry of Sustainable Homes though pictograms illustrating the respective four methods in each phase.

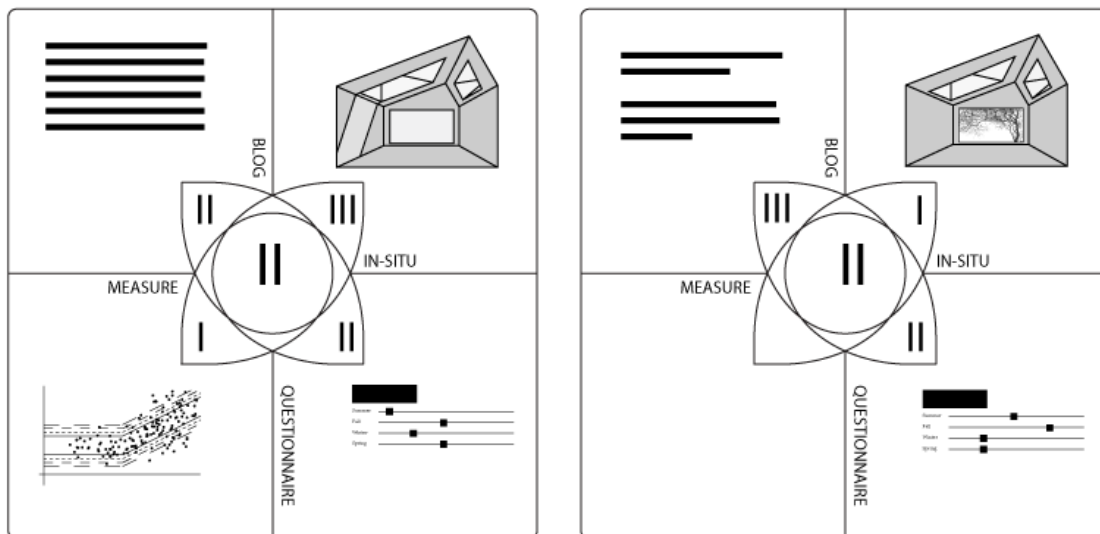
I) IDENTIFY show the four methods and knowledge fields identifies to enquire perceived indoor environment. From the right, respectively In-situ-research, based on a architectural-ethnographic understanding of knowledge, Blog posts based on an occupant-ethnographic and cultural probes fields of knowledge. Questionnaire based on a sociological field of knowledge. Technical measurements based on an engineering-natural-scientific field of knowledge.

II) DESIGN show pictograms of the four designed templates for data collection. From the right scheme for registration of perceived quality following the In-situ research approach. A blank page illustrating the free format of the blog. A questionnaire template divided into themes, question and boxes for checking off. And finally an illustration of continuous logging of technical data.

#### IV) TREAT



#### V) DISSEMINATE



(... continued from previous page ill. 4.7.2)

III) COLLECT show examples of collected data. From the right a photo and descriptive text for the registration scheme. Blog data collected consist in narrative texts on experiences sometimes supplied by photos. Questionnaire data collected are filled in schemes –four from each house. Technical measurement data are collected as files in .csv format in hourly intervals.

IV) TREAT show the analytical approach pursued. Data are collected concurrently through the four different methods, thus in different intervals; through analysis these data sets are completely integrated and treated through thematic means. This means that for instance data on thermal environment are rated together through use of all four methods.

V) DISSEMINATION show the findings of treatment and is the conclusion of the enquiry. For dissemination a dissemination diagram is developed. This compiles examples from all methods able to provide knowledge on the theme of interest. The diagram illustrates rating of enquiry through the individual aspects as well as an average rating.



	IN-SITU RESEARCH	BLOG
D A Y L I G H T & V I E W	<p><b>Data collection methods:</b> In-situ (three day visit) <i>Scheme of Perceived Quality in Sustainable Homes, visual ethnography, visual walk through, sense registration</i></p> <p><b>Light &amp; Shadow elements:</b> Light and shadow, Brightness and darkness, Light space, Anatomy of light, Filtering and temporality <b>View elements:</b> Orientation/ integration, Relation to nature , Connection/transition, Visual privacy, Views</p> <p><b>Rating</b> in compliance with <i>Scheme of Perceived Quality in Sustainable Homes</i> (Olesen &amp; Knudstrup, 2013b) I) Yes, very much; II) To a wide extent; III) Neither/Nor; IV) No, not really; V) No, not at all.</p>	<p><b>Data collection methods:</b> Blog (when occupant like)</p> <p><b>Phrases with content on:</b> brightness; availability of light; direct sunlight; diffuse light; distribution; direction; orientation; weather; size; shape; materials; colour; texture; furnishing; integrated solutions; functions; flexibility; frames; screening; view; visible sky; visible objects and landscape located further away; transmittance; green and nature; near views; visual privacy; orientation; framing; adjustability; control.</p> <p><b>Rating</b> based on thematic analysis in compliance with defined five point scale where V is lowest rating and I is highest rating.</p>
T H E R M A L E N V I R O N...	<p><b>Data collection methods:</b> In-situ (three day visit) <i>Scheme of Perceived Quality in Sustainable Homes, visual ethnography, visual walk through, sense registration</i></p> <p><b>Thermal environment elements:</b> (thermal comfort, variation, fluctuation, shading, draught, materials, heat capacity, spatial organisation, direct solar gains, airing, adjustability, control, system interface)</p> <p><b>Rating</b> in compliance with <i>Scheme of Perceived Quality in Sustainable Homes</i> (Olesen &amp; Knudstrup, 2013b) I) Yes, very much; II) To a wide extent; III) Neither/Nor; IV) No, not really; V) No, not at all.</p>	<p><b>Data collection methods:</b> Blog (when occupant like)</p> <p><b>Phrases with content on:</b> temperature, warmth, warmer, warm, cold, colder, pleasant, thermometer, windows, comfortable, draught and hot.</p> <p><b>Rating</b> based on thematic analysis in compliance with defined five point scale where V is lowest rating and I is highest rating.</p>
A I R  Q U A L I T Y	<p><b>Data collection methods:</b> In-situ (three day visit) <i>Scheme of Perceived Quality in Sustainable Homes, visual ethnography, visual walk through, sense registration</i></p> <p><b>Air quality elements:</b> (fresh air feeling, dampness, mould, materials, window sizes, adjustment, interface, control)</p> <p><b>Rating</b> in compliance with <i>Scheme of Perceived Quality in Sustainable Homes</i> (Olesen &amp; Knudstrup, 2013b) I) Yes, very much; II) To a wide extent; III) Neither/Nor; IV) No, not really; V) No, not at all.</p>	<p><b>Data collection methods:</b> Blog (when occupant like)</p> <p><b>Phrases with content on:</b> fresh air, pleasant, draught, ventilation, windows, pleasant air, opening, stuffy, smell, air quality, mechanical ventilation, breeze, automatic, sick, ill, allergies, irritation and clean.</p> <p><b>Rating</b> based on thematic analysis in compliance with defined five point scale where V is lowest rating and I is highest rating.</p>
A C O U S T I C S	<p><b>Data collection methods:</b> In-situ (three day visit) <i>Scheme of Perceived Quality in Sustainable Homes, visual ethnography, visual walk through, sense registration</i></p> <p><b>Acoustics elements:</b> Sound, noise, opening, windows, outside, hear, listen, raindrops, automatic, others, screening, systems noise</p> <p><b>Rating</b> in compliance with <i>Scheme of Perceived Quality in Sustainable Homes</i> (Olesen &amp; Knudstrup, 2013b) I) Yes, very much; II) To a wide extent; III) Neither/Nor; IV) No, not really; V) No, not at all.</p>	<p><b>Data collection methods:</b> Blog (when occupant like)</p> <p>Phrases with content on: Sound, noise, opening, windows, outside, hear, listen, raindrops, automatic, other occupants, screening and systems noises.</p> <p><b>Rating</b> based on thematic analysis in compliance with defined five point scale where V is lowest rating and I is highest rating.</p>

**III. 4.7.3.(a) Criteria of Enquiry.** Scheme containing instructions on design, collection and treatment of data. Guidelines on data collection and treatment are given for thermal environment, air quality, daylight and view and acoustics for respectively In-situ research and blogs. (From Olesen et al., 2014)

QUESTIONNAIRE	TECHNICAL MEASUREMENTS
<p><b>Data collection methods:</b> Questionnaire (seasonal)</p> <p><b>Main questions:</b> State how satisfied or dissatisfied you are with the temperature conditions? How have you experienced the temperature conditions in the following rooms during the last couple of weeks? Have you experienced varying temperature? How often do you experience being bothered by varying temperatures in the house? How often do you experience being bothered by experiencing downdraughts from the windows?</p> <p>Rating based on thematic analyses presented through graphs following a five-point Likert scale (1932) here V is lowest rating and I is highest rating.</p>	<p><b>Data collection methods:</b> Technical measurement (continous logging)</p> <p>Daylight level measured in lux, fixed ceiling sensors. Simulation in e.g. VELUX Daylight Visualizer.</p> <p><b>Rating</b> in compliance with AH Specification (Gillet et al., 2013) expressed through graphs, and EN 15251 (2007) and five-point scale: I) DF &gt; 5%; II) DF &gt; 3%; III) DF &gt; 2%; IV) DF &gt; 1%; V ≤ 1% on average. Direct sunlight availability for minimum one of the main habitable rooms sunlight provision should be able between autumn and spring equinox: At least: I) 10% ; II) 7.5%; III) 5%; IV) 2.5%; V) &lt; 2.5% ... of probable sunlight hours.</p>
<p><b>Data collection methods:</b> Questionnaire (seasonal)</p> <p><b>Main questions:</b> State how satisfied or dissatisfied you are with the temperature conditions? How have you experienced the temperature conditions in the following rooms during the last couple of weeks? Have you experience varying temperature conditions? How often do you experience being bothered by varying temperatures in the house? How often do you experience being bothered experiencing downdraughts from the windows?</p> <p>Rating based on thematic analyses presented through graphs following a five-point Likert scale (1932) here V is lowest rating and I is highest rating.</p>	<p><b>Data collection methods:</b> Technical measurement (continous logging)</p> <p>Sensors installed in all spaces on walls placed 1.6 m above floorout of direct sunlight and draught.</p> <p><b>Rating</b> in accordance with EN15251 (2006:27). Illustrated as graphs with measured indoor air temperature as function of measured exponentially-weighted running mean outdoor temperature graphs includes four categories defined by three ranges, where <math>\Theta^i</math> is limit value of indoor operative temperature and <math>\Theta^{rm}</math> is running mean outdoor temperature. I: <math>\Theta_i^{max} = 0.33\Theta^{rm} + 18.8 + 2</math> and <math>\Theta_i^{min} = 0.33\Theta^{rm} + 18.8 - 2</math> II: <math>\Theta_i^{max} = 0.33\Theta^{rm} + 18.8 + 3</math> and <math>\Theta_i^{min} = 0.33\Theta^{rm} + 18.8 - 3</math> III: <math>\Theta_i^{max} = 0.33\Theta^{rm} + 18.8 + 4</math> and <math>\Theta_i^{min} = 0.33\Theta^{rm} + 18.8 - 4</math></p>
<p><b>Data collection methods:</b> Questionnaire (seasonal)</p> <p><b>Main questions:</b> How have you experienced the air quality in the house during the last couple of weeks? Have you experienced any problems the air quality being...? What do you usually do if you want to improve air quality? How often do you experience being bothered experiencing downdraughts from windows?</p> <p>Rating based on thematic analyses presented through graphs following a five-point Likert scale (1932) here V is lowest rating and I is highest rating.</p>	<p><b>Data collection methods:</b> Technical measurement (continous logging)</p> <p>Sensors installed in all spaces on walls placed 1.6 m above floorout of direct sunlight and draught.</p> <p>Rating in accordance with EN15251 (2006:36-38). CO<sub>2</sub> level: I) 350 ppm; II) 500 ppm; III) 800 ppm; IV) &lt; 800 ppm ... above outdoor level. Relative humidity: I) 50% - 30%; II) 50-60% or 25-30 %; III) 60-70% or 20-25% IV) &gt; 70% &lt; 20%</p>
<p><b>Data collection methods:</b> Questionnaire (seasonal)</p> <p><b>Main questions:</b> State how satisfied or dissatisfied you are with sound and acoustics conditions in the house? Are you at all bothered by the sound of the systems?</p> <p>Rating based on thematic analyses presented through graphs following a five-point Likert scale (1932) here V is lowest rating and I is highest rating.</p>	<p><b>Data collection methods:</b> Technical measurement (continous logging)</p> <p>ZEB (Olesen et al., 2013b) identifies advise criteria for design values for sound levels from installations in residential buildings: Living room typical range 25-40 dB(A) (default design value 32 dB(A)); Bedroomtypical range 20-35 dB(A)(default design value 32 dB(A))</p> <p>Spot measurements can also be carried out on e.g. reverb, impact; airborne; installation or traffic sound. (DS490:2007)</p>

*III. 4.7.3.(b) Criteria of Enquiry. Scheme containing instructions on design, collection and treatment of data. Guidelines on data collection and treatment are given for thermal environment, air quality, daylight and view and acoustics for respectively questionnaire and technical measurements. (From Olesen et al., 2014)*

## 4.8 Conclusion

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Future sustainable buildings are not merely optimized mechanical constructions with intelligent adjustment systems but houses that imply and require quality in their environments to support and embrace life displayed in and around them. Therefore, it is becoming increasingly central to develop more holistic approach to enquiry and thereby understand the sustainable buildings to provide for that perceptual qualities are balanced with technical abilities.

**Results of this thesis are thus:**

- A model for holistic enquiry of sustainable homes that include occupant perspectives, perceptual quality and technical ability.
- Design of a combined questionnaire and blog approach to collect, treat and explore occupant perspectives.
- Including perceived quality in enquiry of sustainable architecture with a more tangible approach to collect, treat, disseminate and explore aspects of perceptual, sensuous and qualitative nature.
- Focus on aspects of variability in enquiry of sustainable architecture.

### **Conclusion on the Model for Enquiry of Sustainable Homes:**

- The developed and tested Model for Enquiry of Sustainable Homes offers a more complete illustration of the sustainability of a house than either of the tested methods are able to do on its own.
- Knowledge from in-situ research, blogs and questionnaire can provide valuable arguments for sustainability on a level somewhat comparable to technical measurements.
- Research in sustainable buildings should focus more on perceptual, social and everyday perspectives – here lie answers to how future sustainable environments can be solved to give more than they take.

### **This model differs from its predecessors on a range of aspects including:**

- Considers content rather than approach. Based on a pragmatic world view, the model is based on applying what is appropriate in order to enquire the theme of interest to the fullest.
- Introduces assessment of perceived quality.
- Introduces double perspective on occupant experiences by combining questionnaire with the new blog approach.
- Introduces an aspect of variability by collecting data over (longer) time.

## 4.9 Perspectives

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### Recommendations

#### **Full-scale enquiries**

The work in this thesis is based on following and enquiring realised suggestions of what the built environment of the future: three Model Home 2020 homes. This approach is considered central in creating occupant based explorations and enquiries made through this work. This research therefore recommends that even more solutions are tested in real life on real occupants as dimensions, perception and experiences by occupants are not, currently, possible to simulate or capture in other manners.

#### **Recommendations for University**

Research in the field between technical and perceived quality is central if both engineering and architectural professional are to be able to solve the puzzles of future sustainable built environment and life-form. This research suggests researches to increase collaboration between technical, social and artistic knowledge fields even more than it is today. Further, this project suggests research to include aspects of perception, variability and transition across professional barriers, as these are central concepts in solving environmental and architectural challenges of the future. The human being should be the centre of attention from which all branches of research should unfold.

#### **Recommendation for Industry**

As the built Model Home 2020 examples of future sustainable housing show, it is very possible to create beautiful sustainable buildings where new surfaces and products can in fact add to the perceived quality of the spaces created. However, the buildings enquired here are large, high-end and inevitable expensive. Recommendations are to integrate knowledge and learning from these State-of-the-Art homes to create better and more profitable solutions. Accessible products of high technical and perceptual quality can open a market for integrating energy efficient, smart and qualitative solutions in everyday life.

#### **Recommendation for policy makers**

This research has been fortunate enough to follow real families living in real houses through an entire year. Thereby, aspects of real life have been exposed. But not through enquiries by the methods normally applied when aiming at policy making. Here, methods from the social world have provided access to aspects of perceived sustainability and occupants' life. This approach might be useful in policy making if legislation and standardisation should adapt to the more holistic and balanced direction sustainability is moving towards.

## Suggestions for future work

### **Balanced enquiries**

Sustainable architecture is moving towards a more balanced nature where social, functional and perceptual aspects are gaining space from the technological lead. Several aspects, therefore, could and should be included in enquiry of sustainable homes in order to be represented when suitability is, inevitably, weighed up. This work suggests that future work on sustainability should be widely founded; and include even more aspects and methods than this work has managed. Aspects of perception and technical ability are central.

### **The human in architecture**

The key to solving sustainable environments lie with the human being why future work should focus even more on relations between human being, perceived quality and technical ability. By researching the mind, desires and needs of human beings this work foresees that a re-cultivation of the human factor can provide solutions to future spaces and everyday life. Here, a central aspect is to create solutions for functionality as insulation and technology are taking up more and more space. Such solution should be in focus.

### **Human and nature**

Relation between human and nature through this work is based on the return to the human factor as by Nordic Regionalists such as Alvar Aalto, Jørn Utzon and Norberg-Shultz. But there are several other ways to enquire and explore this relation, for instance though a tectonic approach such as Frampton. A new way approach to base architecture on this relation built on Biomimicry (Pawlyn, 2012). Biomimicry steps outside conventional architectural thinking to looking, leaning and be inspired from solution in nature aiming at more effectively solving to future challenges such as energy consumption and ventilation.

### **Variability as a constant in enquiry**

Though this work it was found that dynamic aspects and variability of the environments people are and live in influence the way they perceived these elements. Thus, not too many aspects of variability are integrated in enquiry. Still, many simulation tools hold possibility to simulate different aspects over time thus the simulation engines are commonly based on databases representing average values of weather such as sun height on the sky or hours of sun though the year. This lack a variability resembling the actual unpredictability of nature. The central aspect of variability, however, remains



the human nature and actions. A database on simulation possibilities of human behaviour should be developed containing variable behavioural patterns.

#### **Focus on feedback a motivational to user behaviour**

Though this work it is found that live feedback on users own behaviour on energy use and indoor environment can be motivating as this help illuminating relation between behaviour and consumption as a consequence hereof. More enquiries in automation and feedback from such systems and knowledge could possible provide valuable knowledge on what aspects to accentuate or attenuate to provide for best possible and most sustainable behaviour.

#### **More focus on perception**

In order to understand the human being more into detail, a focus on perception is suggested. Through understanding human perception, possibly also in a medical sense where current research is rapidly developing, there might be answers to creating better and more sustainable solutions for the future. Not merely in a kWh way, but in a complex way of encountering the environment.

#### **Health**

The enquiries on occupant perspectives reveal issues of health as important to some of the occupants. Experiences that your child has less colds, better sleep or has medication for allergies reduced are illustrated as really important aspects of life in these houses. Just imagine, if sustainable build environments of the future could help people get better and en general more healthy. This is a personal gains, but potentially also an enormous (economic) gain for society. Research in this area is encouraged by this work.

#### **Acoustics and aural quality of space and products**

The work though this thesis show that acoustics are not measured by the technical measurements setup proposed, yet the remaining methods point to acoustics as central aspects of wellbeing and occasionally elements of annoyance. In development of products for building industry there is focus on these aspects with legislative requirements for sound levels. This work suggests to also integrating measurements on aspects of acoustics and sounds as long term measurements in future Model Home 2020 project, as it is believed central aspects of knowledge on wellbeing could be found here.

#### **Renovation**

One of the three houses enquired through the work, LichtAktiv Haus near Hamburg in Germany, is a renovation project. The settlers' double-house from the post war period is transformed into a bright example of what renovation can bring to the existing build environment. This work recommends more focus on the existing built environment as here lays a truly great potential.

*Next page (100)*

#### **Ill. 4.9.1. The human in architecture**

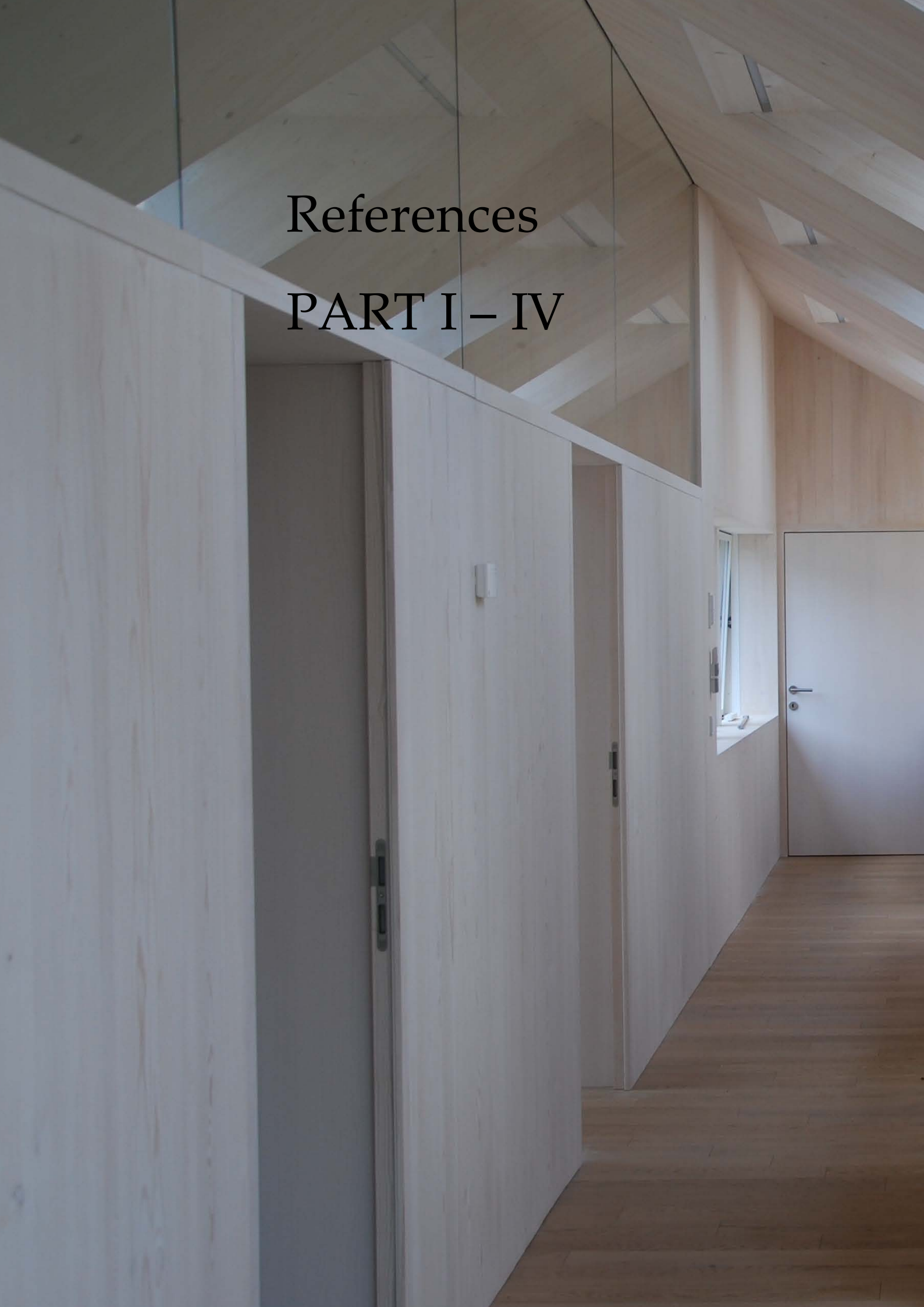
*Even though the human being is not present, physically, when designs for homes are developed, it is central to also consider aspects of everyday functionality – how are users and their things going to fit into the design when the house is also intended to support a sustainable everyday life?*

*Maison Air et Lumière, France, upstairs mezzanine is used as home office, TV-room and playroom with children toys and a football table.*



# References

## PART I – IV







## 4.10 References

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### *Previous spread (101-102)*

#### *Ill. 4.10.1. Perspectives in light*

*Elements of architecture; material, space, shape, light, shades, shadows, course and perspective come together in the effect of space.*

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## PART V | Articles





## 5.0 Articles

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### Publication #1

#### ***Exploring a Model for Enquiry of Sustainable Homes through Indoor Environmental Aspects***

Gitte Gylling Olesen, Mary-Ann Knudstrup, Per K. Heiselberg & Jens Christoffersen (2014)

Submitted to *Indoor and Built Environment*.

### Publication #2

#### ***Encountering Sustainable Functionalism: Feedback as a Method to Raise Awareness on Energy Use and Indoor Environmental Aspects***

Gitte Gylling Olesen, Mary-Ann Knudstrup, Per K. Heiselberg & Jens Christoffersen (2013)

Submitted to *Architectural Science Review*.

### Publication #3

#### ***Enquiring Perceived Quality in Sustainable Architecture: A More Tangible Approach***

Gitte Gylling Olesen and Mary-Ann Knudstrup (2013)

Submitted to *The Journal of Architecture*.

### Publication #4

#### ***Aesthetic Quality in Sustainable Houses: Sensory Experiences of Atmospheres.***

Gitte Gylling H. Olesen & Mary-Ann Knudstrup (2013)

Accepted, awaiting publication in conference proceeding in collaboration with AKADEMIKA.no (delayed)

### Publication #5

#### ***Measuring Sustainable Homes – A Mixed Methods Approach***

Gitte Gylling Olesen, Mary-Ann Knudstrup, Per K. Heiselberg & Ellen K. Hansen (2011)

Conference proceedings: *Considering Research: Reflecting upon current themes in architectural research*, Architectural Research Centres Consortium, Detroit, USA, 2011

### Publication #6

#### ***Holistic Evaluation of Sustainable Buildings through a Symbiosis of Quantitative and Qualitative Assessment Methods***

Gitte Gylling Olesen, Mary-Ann Knudstrup, Per K. Heiselberg & Ellen K. Hansen (2011)

Conference Proceeding of 27<sup>th</sup> Conference on Passive and Low Energy Architecture PLEA 2011, Conference proceedings: *Architecture and Sustainable Development*, vol.2, Belgium, 2011

*Exploring a Model for Enquiry of Sustainable Homes through Indoor Environmental Aspects*

Gitte Gylling Olesen, Mary-Ann Knudstrup, Per K. Heiselberg & Jens Christoffersen (2014)

Submitted to Indoor and Built Environment, Sage Publications

Please notice:

Enlarged figures are presented in elongation of the article, as the figures in the article layout can be difficult to see clearly.

# Exploring a Model for Enquiry of Sustainable Homes through Indoor Environmental Aspects

## Key words

Enquiry, Home, Indoor environment, In-use, Mixed Methods research, Quantitative methods, Qualitative methods, Sustainable

## Abstract

*Ability to weigh up sustainability of buildings is gaining significance as regards financial, political and commercial value. Practice thereby needs tools to enquire, illustrate and communicate this information. This work suggests combining methods in a mixed approach to provide an expanded understanding of buildings through enquiry compared to what methods can reveal unconnectedly and convey a more whole illustration. A model for enquiry that integrates methods from different fields of knowledge is proposed compiling an approach with inherent social, technical, perceptual and aesthetic qualities. The aim is to resemble the complexity of buildings to a wider extent than enquiry models do in general. The paper explores the proposed model by studying indoor environment in three inhabited energy plus Model Home 2020 houses rooted in Active House vision. Findings of these in-use enquiries show the homes have generally very good thermal environments and varying air quality. Daylight and visual environments/view are of great influence to the perception of the houses and are related to aspects of health and wellbeing. Acoustics could be improved and should be area of focus forward. The model makes evident that different knowledge fields have different strengths dependent on theme of interest.*

## Introduction

Architecture is a field constituted by multiple ways of knowing. It is a field where successful design is compiled by a complexity of technical, functional, physical, physiological, perceptual and sensuous qualities [1, 2]. With sustainability more layers of complexity are added to architecture as demands of energy reduction and production, increasing legislative restrictions and automation moves in [3-10].

Construction, running and maintenance of the built environment accounts for up to 40 percent of energy consumed in the Western World and the primary part of energy used come from fossil fuels. [3, 4, 5] At the same time people spend more and more time indoors, in the Northern countries up to 90 percent of time while 30 percent of buildings do not contribute to establishing healthy indoor environments. [6] Buildings are central in consumption of energy, while also in creating homes for people to live in.

### Quantification of life

The first technological innovation of the industrial revolution around the 1900s, electrical lighting and heating/cooling, made it possible to create artificial improvements to the indoor environment, which previously had been determined primarily by the temperament of climate. With this offset efforts to improve indoor environment in buildings has been developing since. [6, 11] Hawkes points out that these inventions

mark the opportunity to redefine relationships between climate and architecture and thereby created a fundamental change in architecture, also characterized by Lewis Mumford as *'the quantification of life'* [7, p. 24]. The shift created the foundation for standardisation and a turn toward regarding technical aspects superior. Pallasmaa argues: *'In becoming a specialist profession, architecture has gradually detached itself from its intentional background, evolving into a discipline more and more fully determined by its own rules and value systems. Architecture is now a field of technology that still ventures to believe itself a form of free artistic expression'* [12, p. 87]. Despite this course many of the references enquired entail that sensuous qualities are central to creating architecture; Bluysen even point out: *'In fact, historically, these parameters received the most attention when designing a building'* [6, p.4].

Then, how can it be provided that sustainable buildings are not merely valued on their ability to comply with 'the quantification of life' but also contribute to qualify the life unfolded in them?

### Hypothesis and aim

This enquiry hypothesize that by compiling assessment approaches in a dynamic integral mixed methods setup, it is possible to include aspects of more perceptual character and thereby provide for balance of quantitative and qualitative aspects.

This paper differs from previous research by approaching to capture complexity of homes and users through a dynamic, integral mixed methods approach. The aim is to create a model for enquiry of sustainable homes directed at practice; that includes aspects of perceived quality on the same level as technical ability, include user perspectives and is based on dynamic means to comply best possibly with the current development of sustainable architecture.

The model is designed for Model Home 2020 [21] houses rooted in Active House vision [25].

## Enquiry of buildings

During the past centuries evaluation and enquiry of building performance has developed leading to a wide range of simulation programs and assessment systems in extensive numbers and varieties. [3,13-15] Enquiry of sustainable buildings has developed rapidly since the Brundtland report was formulated in 1987 [10], pushed by increase in legislative demands; and it has become generally accepted that a stationary approach to assessment is the right approach [16,17]. Often, assessment is performed pre-construction and dynamic variables are disregarded to a wide extent. But, the life that unfolds in a house, the passing of second, hour, day, season and year are all dynamics [30; 31]. With ongoing development of intelligent systematic solutions to controlling and adapting exterior

and interior environments of buildings, time is running out for stationary assessment approaches. They are not able to capture complexities of sustainability which is not merely a matter of technical ability, but also of functional, physical, physiological, perceptual and sensuous performance. Thus, these assessment methods are not created as instruments for comprehensive enquiry of architectural quality but as labels that describes what they are specifically designed for. Thereby, need for dynamics and multifaceted assessment approaches emerge as it is relevant and necessary include variability in assessment of buildings in-use. Post Occupant Evaluation (POE) [37-39] is becoming increasingly used enquiring homes after people have moved into them [32-35]. Multiple methods enquiry of homes in-use is also more widely used and examples can be found worldwide where a range of POEs, methods from social sciences such as interviews or questionnaires or technical measurements [16] are used together. The IEA Task 40 21 project has identified more than 300 built net zero energy houses worldwide [32; 36], all examples of houses designed for future challenges of sustainable life form. These project are enquired by different approaches. Examples are the Danish '*Comfort houses*' [18, 19] and '*Home for Life*' [4, 20]). These research projects imply application of numerous methods provide knowledge on several levels. They illustrate how technical measurement can be supplied by methods from social sciences such as

questionnaires or interviews. Thereby, research problems are explored from several perspectives where knowledge obtained through technical means can be elaborated through for instance user statements, adding layers of qualitative knowledge. The approach has proven valuable to provide an expanded understanding of the actual in-use experiences and to explain technical conditions [9, 13, 18]. In United Kingdom 'BASF House' and 'The Uptown Homes project' [40] are enquired by means of what is named first-person research coupled with technical sensors (48 sensors installed to measure). Poblete writes: 'Hands on' experience makes it possible to identify, select and verify real and direct problems that expect the expected performance of sustainable homes. Another English research project suggests using BIM (Building Information Modelling) and sensing devices tested on 'Salford Energy House' [41] focusing on optimising evaluation models based on sensory measured data. In Scotland 'Orkney Houses' and 'Glasgow flats' are enquired through onsite technical measurements paired with questionnaire aiming at developing a three level physical and social survey methodology [42]. Drexler and El Khouli [35] makes enquiries of 'Holistic Housing' by assessing 15 house across the world using 'The Housing Quality Barometer' [43] where they use a scale of five quality rating levels for assessing 79 criteria. The scale includes levels: I) Exemplary/best practice; II) Innovative/target value; III)

Above average/good; IV) Standard/reference value; and V) Below average/critical value.

The brief overview above illustrate that several methods are applied to enquiring aspects of sustainable environments from quantitative and qualitative as well as mixed methods approaches. These imply good intentions and insights that sustainability is not merely a technical issue, as was the main focus though years; and with the developing pace of sustainable solutions to creating homes, more mixed methods enquiry seems appropriate to also include social, technical, perceptual, functional and aesthetic qualities

With an increasing focus on integrated design and increasingly complex building solutions the course illuminated for sure point in the right direction to illustrate the complex solutions of sustainability. Still, it would be desirable to integrate more different perspectives to enquiry of different elements of sustainability. As described above, sustainable architecture is a complex field of knowledge; therefore, it requires a wide perspective though design and construction as well as though enquiry. This work therefore proposes a model which includes several perspectives on dynamic in-use aspects of sustainable homes; through occupant perspectives, perceptual qualities based on in-situ registration and technical ability based on measurements.

## Materials

Empirical enquiry is based on query of three *Model Homes 2020* houses [21]; respectively *LichtAktiv Haus* in Hamburg, Germany (LAH) [22], *Sunlighthouse* in Pressbaum, Austria (SLH) [23] and *Maison Air et Lumière* in Verrieres Le Buisson, France (MAL) [24]. All are single-family houses designed and constructed in compliance with the Active House vision [25]: *'Active House is a vision of buildings that create healthier and more comfortable lives for their occupants without impacting negatively on the climate – moving us towards a cleaner, healthier and safer world.'*

Designed as energy plus the houses produce more energy than they consume and technologies such as photo voltaic and solar

panels are integrated after optimisation by passive means have reduced requirement for energy. Large windows, plenty of daylight and natural ventilation are main design aspects. Automated systems constantly monitor and adjust components to regulate indoor environment to comply best possible with present comfort conditions. Test families move in to live in each of the houses. Test families are chosen based on extensive evaluation to resemble an average family from the respective areas [26]. Characteristics displayed in Figure 1. The houses have integrated automatic steering systems where technical equipment for censoring and logging data to adjust the systems is already installed and part of house design.





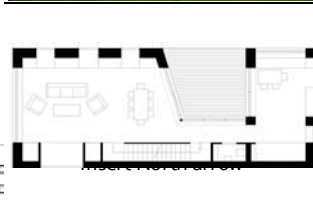
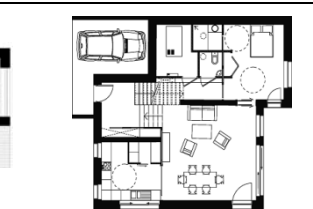
	LICHTAKTIV HAUS, LAH	SUNLIGHTHOUSE, SLH	MAISON AIR ET LUMIERE, MAL
Photo of exterior			
Main floor plan			
Description	Renovated double house + addition	New-built single-family house	New-built single-family house
Size m <sup>2</sup> b/n	189 m <sup>2</sup> / 132 m <sup>2</sup>	304 m <sup>2</sup> / 201 m <sup>2</sup>	234 m <sup>2</sup> / 173 m <sup>2</sup>
Floors	3 (old) / 1 (new)	3	2 (+ 1/2)
Family	1 male, 1 female, 2 boys (6&8)	1 male, 1 female, 2 boys (2&5)	1 male, 1 female, 2 boys (4&7)

Figure 1: **Characteristics of the three Model Homes 2020 houses.** Houses presented through photo of exteriors, main floor plan, description, size and number of floors; and characteristics of the family.



## Methods

### **Proposing a model for holistic assessment**

This chapter suggests a model for assessment of sustainable homes in-use; based on a thematic, integral mixed methods approach.

### **Aim**

The aim of the model is to create an approach to assessment of sustainable homes which include dynamic in-use aspects through occupant perspectives, perceptual qualities based on in-situ registration and technical ability based on measurements.

The logic behind the model is to create balance between science and practice by creating a simplified model applicable to practice within limited time and financial resources which is also scientifically well-founded, methodological accurate and supports validity in enquiries.

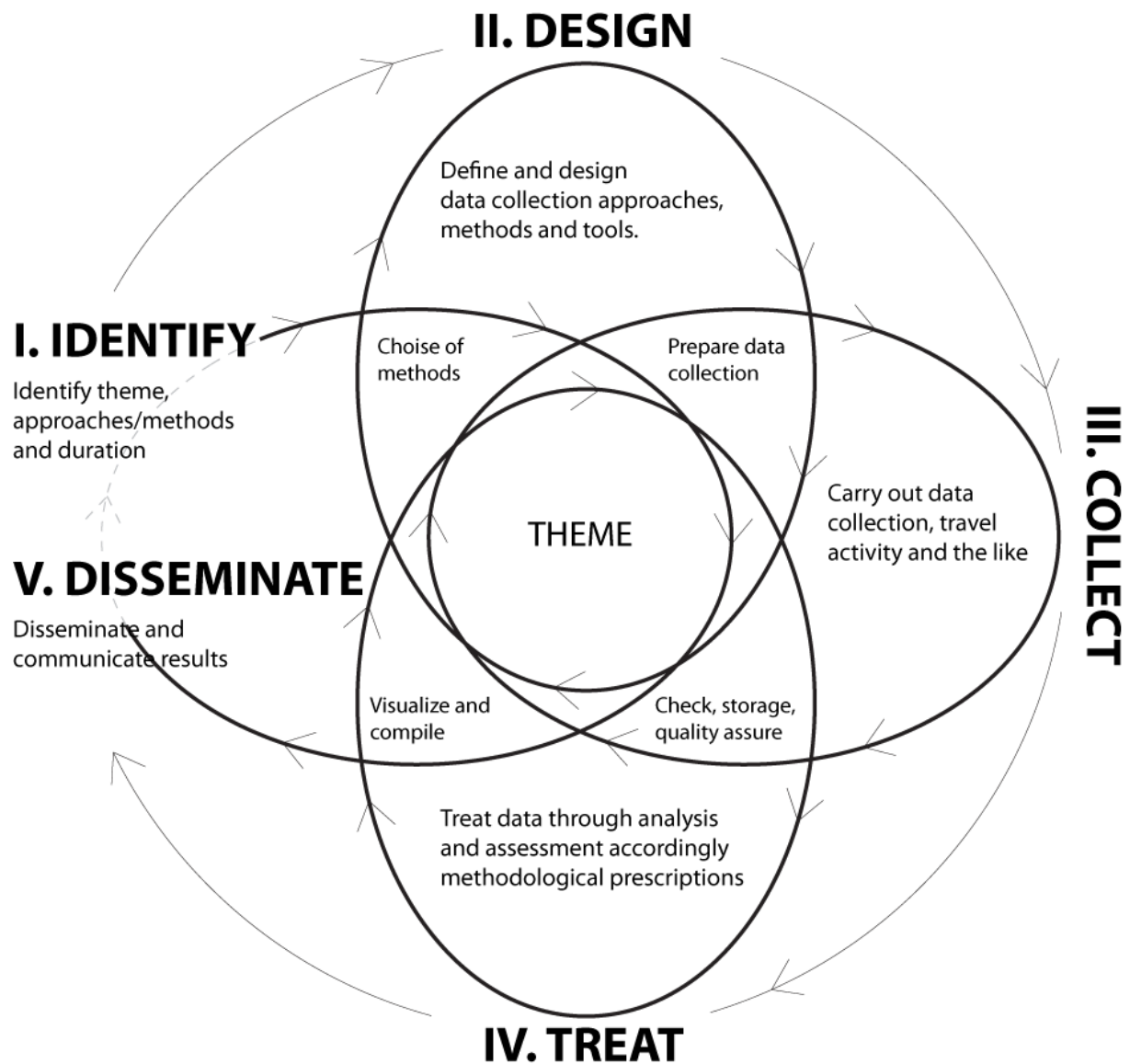
### **Foundation**

Foundation for the model is a holistic view point aiming to establish encounters in the sphere between empirical analytical and phenomenological worldviews [27].

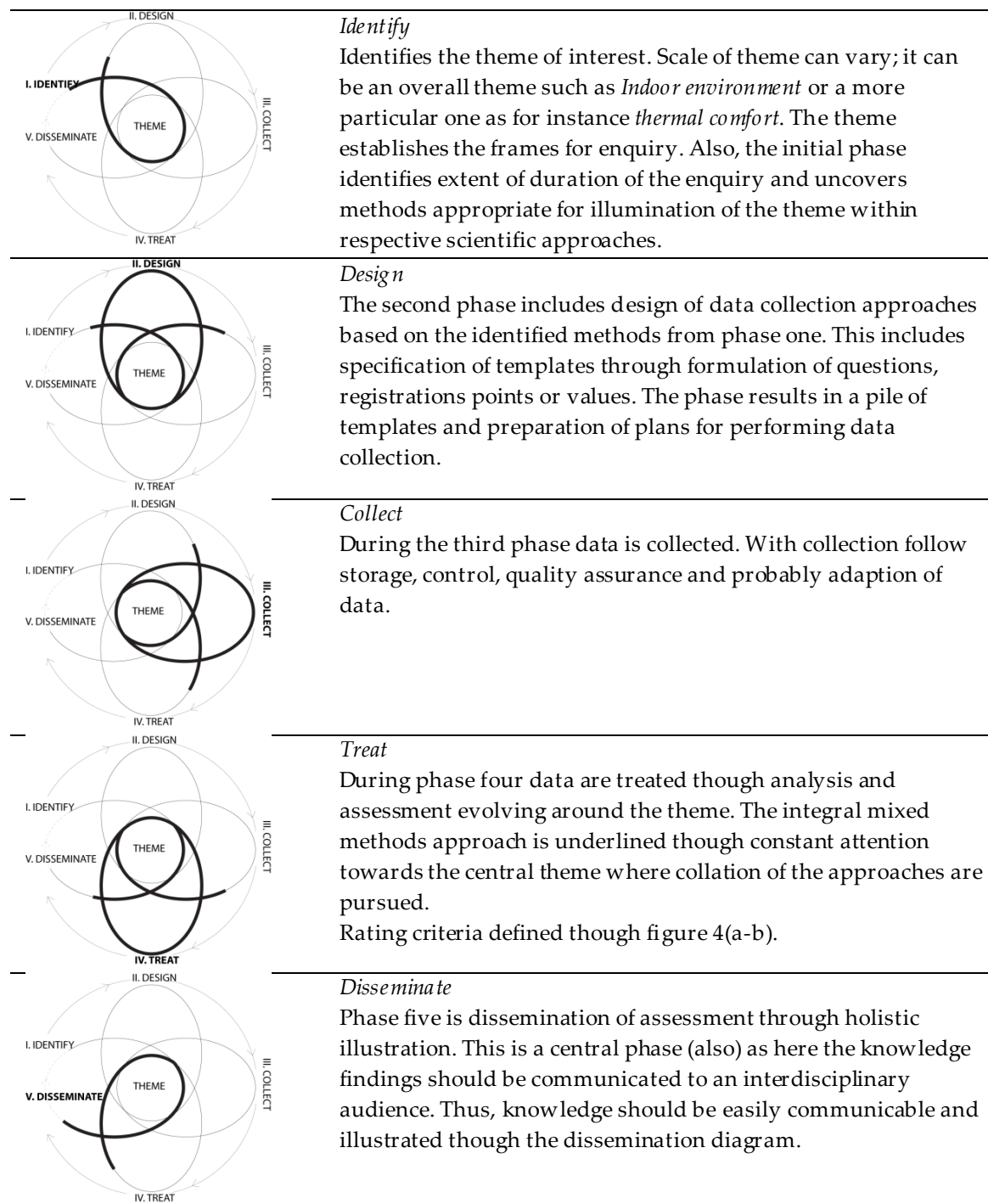
The model represents a systematic methodological approach designed following a Concurrent Transformative Strategy of inquiry in a mixed methods setup [28, p. 215]. The reason for this mixed methods approach is to establish possibility to reveal the same problem from various perspectives simultaneously making the approaches support or contradict each other, an interpretation supported by Rabinowitz: *'Qualitative and quantitative methods are, in fact, complementary. Each has strengths and weaknesses that the other doesn't, and together, they can present a clearer picture of the situation than either would alone.'* [29] The model thereby provides opportunity to identify casual connections between data from different methods possibly identifying the cause of an issue in one dataset within another.

### **Design of a model**

The model is designed as a five phase structure embracing the respective phases: Identify; Design; Collect; Treat; Disseminate. Focuses orbit around a theme which each step continuously consult through an integral and iterative process. This orbiting is illustrated in Figure 3.



**Figure 2. Model of Enquiry.** The proposed model of enquiry is based on a five phase structure of 'identify', 'design', 'collect', 'treat' and 'disseminate'. The model is based on an iterative process where the theme of interest (centered in the figure) is continuously consulted through all aspects of the enquiry. Thereby, the different explorations become about a theme of interest rather than about one specific scientific field of knowledge and its classically coherent methods.



**Figure 3. Phases of the Model of Enquiry.** Diagrams to the left illustrate the area of the model covered by the phase; while the column to the right provide a short description of the parameter in question.

## Empirical enquiry

To explore possibilities and limitations to the proposed model it is empirically tested. The purpose of this empirical enquiry is to explore if the model creates a more holistic process and illustration of sustainability than the methods would suggest individually. Also, the enquiry seeks to specify the model and thereby making it operational through exploring a specific theme.

### Identify, design, collect, treat, disseminate

As illustrated in Figure 3, each phase of the model of enquiry have a range of steps to carry through. The following will elaborate identification, design, collection, treatment and dissemination procedures. These phases are supported by figures 4(a-b) which also specifies 'Criteria for Enquiry'.

The theme of interest is Indoor environment including thermal environment, air quality, daylight, view and acoustics.

To approach enquiry from several perspectives four fields of knowledge, and thereby four methods, are employed respectively in-situ research, blog research, questionnaire survey, and technical measurement. The following sections will elaborate on these approaches by specifying the respective methods selected to include these perspectives in the compiled model for enquiry of sustainable homes.

### In-situ research: enquiring perceived quality

In-situ research is a term for a bodily and sensuous enquiry carried out by an architectural professional. The approach is developed through the work-in-progress on enquiry of perceived quality in sustainable homes: a more tangible approach. The work compiles a scheme for collection, treatment and dissemination of data consisting of photos, text and ratings under the terms *Motif*, *Worth* and *Extent*. Elements of interest in the scheme are perception, relation, composition, surface, light & shadow, variability and utility. Enquiry is carried out once as a three day visit with overnight stay if possible.

#### Criteria for rating (see figure 4(a))

The scheme for enquiry of perceived quality is also a rating a dissemination tool. Column four *Extent* is thereby for valuation of the extent to the element is experienced to add to perceived quality. Thereby, this column represents a quantification of the identified elements of perceived quality.

Rating is proposed as a five point scale with I as best rating and V as least good rating. The scale shows to what *Extent* the element is identified contribute to the perceived quality of home: I) *Yes, very much*; I) *Yes, to a wide extent*; I) *Neither/nor*; IV) *No, not really*; and V) *No, not at all*.

### **Blog: Occupant experiences**

Blog and questionnaire approaches are both applied with an aim of collecting occupant experiences developed through an ongoing study in 'Encountering Sustainable Functionalism: Feedback as a Method to Raise Awareness on Energy Use and Indoor Environment in Automated Homes'. Blog is an online based diary where occupants in the house as frequently as they feel like post texts and photos on their experiences of living in the house. Generation of data thereby happens continuously and collection is made straight off the blog. Following, data undergo thematic analyses and are represented as quotes and photos, to keep their narrative character.

#### **Criteria for rating (see figure 4(a))**

Criteria for rating are somewhat similar to the condition made in relation to In-situ research. Rating based on thematic analysis in compliance with defined five point scale where V is lowest rating and I is highest. Rating is based on motivated illustration on the occupants' opinion on the theme elements of enquiry. *Purely positive quotes such as: "We have natural light in rooms without window. (...) The light is soft and does not attack the eyes. It's very nice every day" (MAL, 17th February 2013)* would be rated I. While a quote such as: *"Uuuuhh, at -8 degrees you have to be quite brave when the window suddenly automatically opens..." (Occupants in LAH, 2<sup>nd</sup> February 2012, blog)* would be rated IV. Identification and listing of all blog posts on

a subject and following individual rating cause for an average rating for the theme. Rating can be based on one or numerous blog quotes – the more samples the average is created from, the better foundation for the rating.

### **Questionnaire: Occupant experiences**

Questionnaire survey is developed on basis of pilot studies of a similar house in combination with workshop on composed hypotheses on occupant experiences of life in homes developed from the Active House vision [25]. Data collection is carried out seasonally and thereby four times during the test year the family lives in the house allowing capturing and exploring variation on a seasonal basis.

#### **Criteria for rating (see figure 4(b))**

The questions used are based on multiple sets of Likert scales [45] for instance categorized such as: Very satisfied; Satisfied; Neither satisfied nor dissatisfied; Dissatisfied; Very dissatisfied; or like this: Very rarely; Rarely; Occasionally; Frequently; Very frequently. The questionnaire also use three, four or multiple choice lists, then rating is compiled as the best estimate resembling the five point scale as best as possible.

### **Technical measurement: technical ability**

To cover aspects of technical character measurements are performed as made possible through the setup in the houses [21-25]. Due to the character of the installation it

is possible to continuously log data and following extract data in desired intervals. Hourly data extractions are made, as this interval provides opportunity to explore aspects of variation without going too much into details. Data are treated accordingly instruction in Figure 5 (b)

#### **Criteria for rating (see figure 4(b))**

Thermal environment is rated following EN 15251 [16], Active House Specification (AH) [47] and criteria based on Definition of the indoor environmental quality used for Net Zero Energy Buildings (ZEB) [46]. Air quality is rated accordingly following EN 15251 [16].

Daylight level and direct sunlight availability are rated in compliance with Active House Specification (AH) [47] and ZEB [46] which is an elaboration over EN 15251 [16]. For residential buildings ZEB [46] state criteria for direct sunlight availability: 'To reduce the prevalence of SAD (seasonal Affective Disorder; "winter depression"), high light levels are particularly important during winter. For minimum one of the main habitable rooms in residential buildings direct sunlight should be available from fall to spring equinox:' [46]

View is not rated though technical measurement in this enquiry.

#### **Acoustics**

Acoustics have not been a focal point though this work as no sensor equipment was

installed for such (due to the privacy of the occupants). Yet suggestion for design criteria are listed in figure 4(b) based on Danish Standard DS 490:2007 [47]. This is stated to point to possibilities in enquiring acoustics as well as the remaining aspects of indoor environment.

#### **Dissemination diagram**

With an aim of creating a common dissemination tool for the perspectives included through the Model for Enquiry a dissemination diagram is compiled which to gathers and portrays all enquiry findings in one illustration. The diagram has one field for exemplifying findings; this might be a figure, picture or quote; one field for stating the rating of the specific enquiry; and one field for an average of ratings. The diagram is exemplified in use in figure 9.

## **Results**

This results section will first present main results of the enquiries by showcasing findings on thermal environment air quality and view in the three Model Home 2020 homes; as due to the extent of data and character of figures were not possible to illustrate all findings and one house is selected as to represent the common findings on each aspect. The selected examples shown in the figures are intended to illustrate and support findings. Following, a dissemination diagram is illustrated on LichtAktiv Haus while findings are summoned up for all houses.

	IN-SITU RESEARCH	BLOG
D A Y L I G H T & V I E W	<p><b>Data collection methods: In-situ</b> (three day visit) <i>Scheme of Perceived Quality in Sustainable Homes, visual ethnography, visual walk through, sense registration</i></p> <p><b>Light &amp; Shadow elements:</b> Light and shadow, Brightness and darkness, Light space, Anatomy of light, Filtering and temporality <b>View elements:</b> Orientation/ integration, Relation to nature, Connection/transition, Visual privacy, Views</p> <p><b>Rating</b> in compliance with <i>Scheme of Perceived Quality in Sustainable Homes</i> (Olesen &amp; Knudstrup, 2013b) I) Yes, very much; II) To a wide extent; III) Neither/Nor; IV) No, not really; V) No, not at all.</p>	<p><b>Data collection methods:</b> Blog (when occupant like)</p> <p><b>Phrases with content on:</b> brightness; availability of light; direct sunlight; diffuse light; distribution; direction; orientation; weather; size; shape; materials; colour; texture; furnishing; integrated solutions; functions; flexibility; frames; screening; view; visible sky; visible objects and landscape located further away; transmittance; green and nature; near views; visual privacy; orientation; framing; adjustability; control.</p> <p><b>Rating</b> based on thematic analysis in compliance with defined five point scale where V is lowest rating and I is highest rating.</p>
T H E R M A L E N V I R O N...	<p><b>Data collection methods: In-situ</b> (three day visit) <i>Scheme of Perceived Quality in Sustainable Homes, visual ethnography, visual walk through, sense registration</i></p> <p><b>Thermal environment elements:</b> (thermal comfort, variation, fluctuation, shading, draught, materials, heat capacity, spatial organisation, direct solar gains, airing, adjustability, control, system interface)</p> <p><b>Rating</b> in compliance with <i>Scheme of Perceived Quality in Sustainable Homes</i> (Olesen &amp; Knudstrup, 2013b) I) Yes, very much; II) To a wide extent; III) Neither/Nor; IV) No, not really; V) No, not at all.</p>	<p><b>Data collection methods:</b> Blog (when occupant like)</p> <p><b>Phrases with content on:</b> temperature, warmth, warmer, warm, cold, colder, pleasant, thermometer, windows, comfortable, draught and hot.</p> <p><b>Rating</b> based on thematic analysis in compliance with defined five point scale where V is lowest rating and I is highest rating.</p>
A I R  Q U A L I T Y	<p><b>Data collection methods: In-situ</b> (three day visit) <i>Scheme of Perceived Quality in Sustainable Homes, visual ethnography, visual walk through, sense registration</i></p> <p><b>Air quality elements:</b> (fresh air feeling, dampness, mould, materials, window sizes, adjustment, interface, control)</p> <p><b>Rating</b> in compliance with <i>Scheme of Perceived Quality in Sustainable Homes</i> (Olesen &amp; Knudstrup, 2013b) I) Yes, very much; II) To a wide extent; III) Neither/Nor; IV) No, not really; V) No, not at all.</p>	<p><b>Data collection methods:</b> Blog (when occupant like)</p> <p><b>Phrases with content on:</b> fresh air, pleasant, draught, ventilation, windows, pleasant air, opening, stuffy, smell, air quality, mechanical ventilation, breeze, automatic, sick, ill, allergies, irritation and clean.</p> <p><b>Rating</b> based on thematic analysis in compliance with defined five point scale where V is lowest rating and I is highest rating.</p>
A C O U S T I C S	<p><b>Data collection methods: In-situ</b> (three day visit) <i>Scheme of Perceived Quality in Sustainable Homes, visual ethnography, visual walk through, sense registration</i></p> <p><b>Acoustics elements:</b> Sound, noise, opening, windows, outside, hear, listen, raindrops, automatic, others, screening, systems noise</p> <p><b>Rating</b> in compliance with <i>Scheme of Perceived Quality in Sustainable Homes</i> (Olesen &amp; Knudstrup, 2013b) I) Yes, very much; II) To a wide extent; III) Neither/Nor; IV) No, not really; V) No, not at all.</p>	<p><b>Data collection methods:</b> Blog (when occupant like)</p> <p><b>Phrases with content on:</b> Sound, noise, opening, windows, outside, hear, listen, raindrops, automatic, other occupants, screening and systems noises.</p> <p><b>Rating</b> based on thematic analysis in compliance with defined five point scale where V is lowest rating and I is highest rating.</p>

**Figure 4(a). Instruction on design, collection and treatment of data.** Guidelines on data collection and treatment are given for thermal environment, air quality, daylight and view and acoustics for respectively In-situ research and blogs.



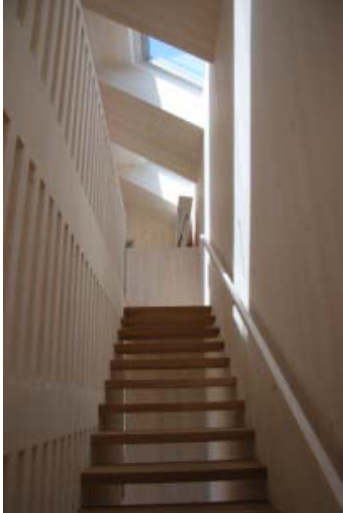


QUESTIONNAIRE	TECHNICAL MEASUREMENTS
<p><b>Data collection methods:</b> Questionnaire (seasonal)</p> <p><b>Main questions:</b> State how satisfied or dissatisfied you are with the temperature conditions? How have you experienced the temperature conditions in the following rooms during the last couple of weeks? Have you experienced varying temperature? How often do you experience being bothered by varying temperatures in the house? How often do you experience being bothered by experiencing draughts from the windows?</p> <p>Rating based on thematic analyses presented through graphs following a five-point Likert scale (1932) here V is lowest rating and I is highest rating.</p>	<p><b>Data collection methods:</b> Technical measurement (continuous logging)</p> <p>Daylight level measured in lux, fixed ceiling sensors. Simulation in e.g. VELUX Daylight Visualizer. <b>Rating</b> in compliance with AH Specification (Gillet et al., 2013) expressed through graphs, and EN 15251 (2007) and five-point scale: I) DF &gt; 5%; II) DF &gt; 3%; III) DF &gt; 2%; IV) DF &gt; 1%; V ≤ 1% on average. Direct sunlight availability for minimum one of the main habitable rooms sunlight provision should be able between autumn and spring equinox: At least: I) 10% ; II) 7.5%; III) 5%; IV) 2.5%; V) &lt; 2.5% ... of probable sunlight hours.</p>
<p><b>Data collection methods:</b> Questionnaire (seasonal)</p> <p><b>Main questions:</b> State how satisfied or dissatisfied you are with the temperature conditions? How have you experienced the temperature conditions in the following rooms during the last couple of weeks? Have you experience varying temperature conditions? How often do you experience being bothered by varying temperatures in the house? How often do you experience being bothered experiencing draughts from the windows?</p> <p>Rating based on thematic analyses presented through graphs following a five-point Likert scale (1932) here V is lowest rating and I is highest rating.</p>	<p><b>Data collection methods:</b> Technical measurement (continuous logging) Sensors installed in all spaces on walls placed 1.6 m above floorout of direct sunlight and draught.</p> <p><b>Rating</b> in accordance with EN15251 (2006:27). Illustrated as graphs with measured indoor air temperature as function of measured exponentially-weighted running mean outdoor temperature graphs includes four categories defined by three ranges, where <math>\Theta^i</math> is limit value of indoor operative temperature and <math>\Theta^{rm}</math> is running mean outdoor temperature. I: <math>\Theta^{i\max} = 0.33\Theta^{rm} + 18.8 + 2</math> and <math>\Theta^{i\min} = 0.33\Theta^{rm} + 18.8 - 2</math> II: <math>\Theta^{i\max} = 0.33\Theta^{rm} + 18.8 + 3</math> and <math>\Theta^{i\min} = 0.33\Theta^{rm} + 18.8 - 3</math> III: <math>\Theta^{i\max} = 0.33\Theta^{rm} + 18.8 + 4</math> and <math>\Theta^{i\min} = 0.33\Theta^{rm} + 18.8 - 4</math></p>
<p><b>Data collection methods:</b> Questionnaire (seasonal)</p> <p><b>Main questions:</b> How have you experienced the air quality in the house during the last couple of weeks? Have you experienced any problems the air quality being...? What do you usually do if you want to improve air quality? How often do you experience being bothered experiencing draughts from windows?</p> <p>Rating based on thematic analyses presented through graphs following a five-point Likert scale (1932) here V is lowest rating and I is highest rating.</p>	<p><b>Data collection methods:</b> Technical measurement (continuous logging)</p> <p>Sensors installed in all spaces on walls placed 1.6 m above floorout of direct sunlight and draught.</p> <p>Rating in accordance with EN15251 (2006:36-38). CO<sub>2</sub> level: I) 350 ppm; II) 500 ppm; III) 800 ppm; IV) &lt; 800 ppm ... above outdoor level. Relative humidity: I) 50% - 30%; II) 50-60% or 25-30 %; III) 60-70% or 20-25% IV) &gt; 70% &lt; 20%</p>
<p><b>Data collection methods:</b> Questionnaire (seasonal)</p> <p><b>Main questions:</b> State how satisfied or dissatisfied you are with sound and acoustics conditions in the house? Are you at all bothered by the sound of the systems?</p> <p>Rating based on thematic analyses presented through graphs following a five-point Likert scale (1932) here V is lowest rating and I is highest rating.</p>	<p><b>Data collection methods:</b> Technical measurement (continuous logging)</p> <p>ZEB (Olesen et al., 2013b) identifies advise criteria for design values for sound levels from installations in residential buildings: Living room typical range 25-40 dB(A) (default design value 32 dB(A)); Bedroomtypical range 20-35 dB(A)(default design value 32 dB(A))</p> <p>Spot measurements can also be carried out on e.g. reverb, impact; airborne; installation or trafic sound. (DS490:2007)</p>

**Figure 4(b). Instruction on design, collection and treatment of data.** Guidelines on data collection and treatment are given for thermal environment, air quality, daylight and view and acoustics for respectively questionnaire and technical measurements.

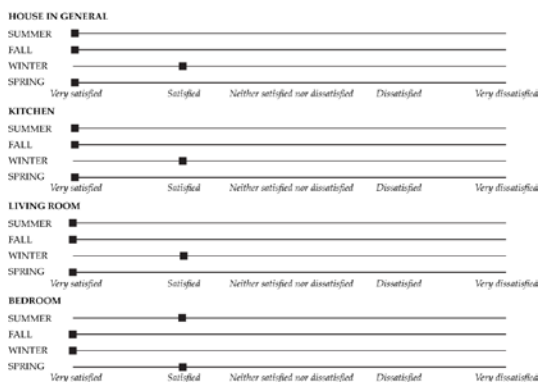
## Thermal environment

Enquiry on thermal comfort is illustrated through data from Sunlighthouse. Thermal comfort is in general experienced thought questionnaires as very *satisfying* or *satisfying across* the houses and conditions are experienced as *about right* and sometimes *varying*. These are nice results especially encountering passive means of natural ventilation and draught which are rarely experienced. Aspects of adjustability are perceived as better though blogs as compared to their rating in questionnaires – a repeating tendency throughout the houses – indicating that occupants comparably describe more positive aspects through their blogs. Distribution of technically measured temperatures fall in the lower part of the desired intervals indicating overheating rarely occur; this is a bit surprising, as the

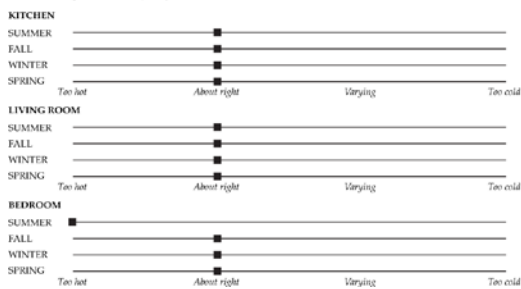
houses all have large glassed areas, and overheating could be expected. Thereby, natural ventilation seemingly work as intended – namely in the Austrian Sunlighthouse and the French Maison Air et Lumière where outdoor temperatures during summer are easily above 30 degrees. At the same time the LichtAktiv Haus, Germany show a bit of trouble in keeping warm during winter. It is rather eye-catching that French Maison Air et Lumière shows the best thermal distribution while here occupants' answers to questionnaire vary the most in degree of satisfaction. In-situ experiences of the house made clear that these houses should not be compared, as each house has been carefully adapted to the climate they are built in – also with regards to establishing the best thermal environment possible driven by natural means.

	<i>Sunlighthouse, Austria</i>		
I N - S I T U	<b>Rating: II</b>	 <p>The tall spaces are a good driver for natural ventilation. This works well in the house; yet can be chilly to walking the stairs.</p>	  <p>Movable shutters on the cupboard wall function as inside sun screening to screen off direct sun and unwanted solar heat gains. Still, it feel quite warm in the house, the floor surfaces in the sun are impossible to step on with bare feet.</p>
	<b>Rating: I</b>	<p>"A big plus is the nocturnal cooling behaviour of the house. Is it cool in the evening the house can very quickly cool down to a comfortable temperature. Through the open-plan staircase, the cool forest air from the basement runs like a chimney through the roof windows up." Ludwig, 3<sup>rd</sup> July 2012</p> <p>"Sunlighthouse holds the temperatures very well despite the many glass surfaces. It will not overheat and then it cools off quickly at night. And that's a good thing." Ludwig 3<sup>rd</sup> July 2012</p>	

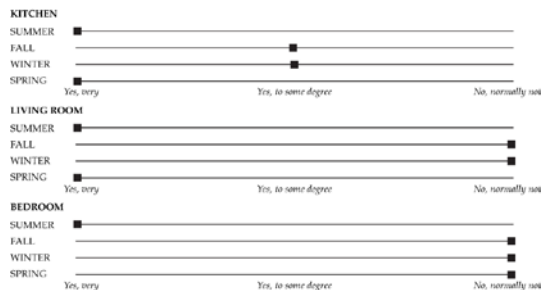
State how satisfied or dissatisfied you are with the temperature conditions in the house in general and in the following rooms



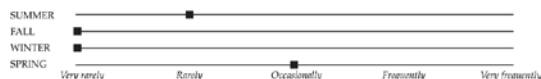
How have you experienced the temperature conditions in the following rooms during the last couple of weeks?



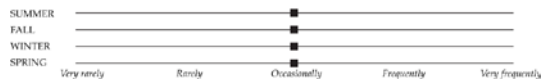
Have you experienced varying temperature conditions in the following rooms?



How often do you experience being bothered by varying temperatures in the house?



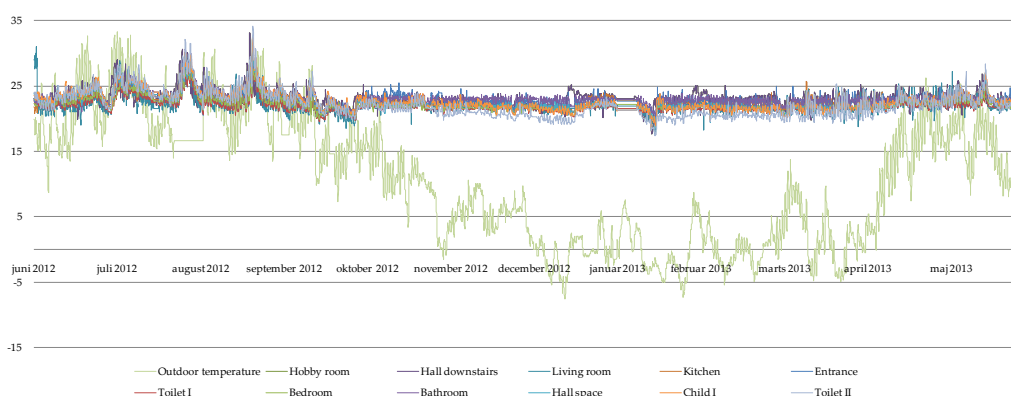
How often do you experience being bothered by experiencing draughts from the windows?

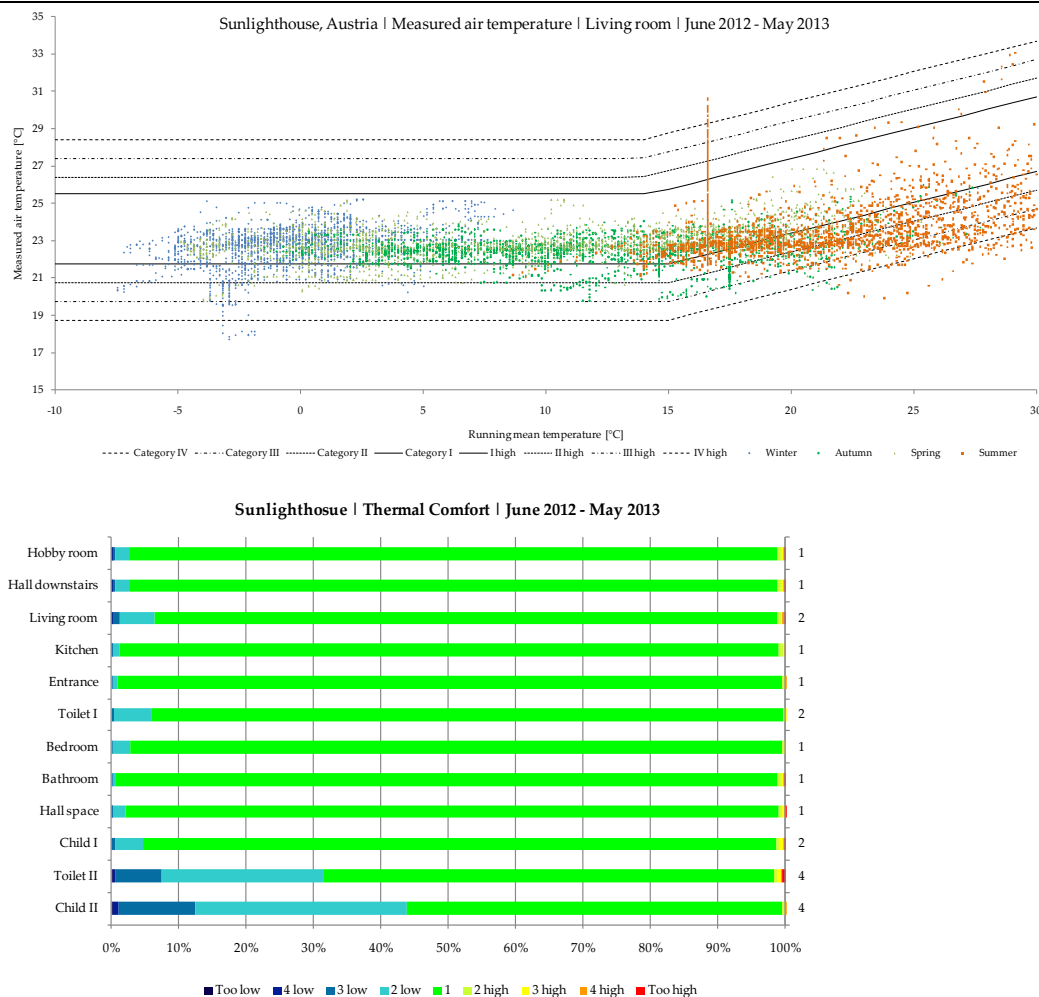


Rating : I

Rating: I

Sunlighthouse | Measured indoor and outdoor temperature | June 2012 - May 2013





**Figure 5. Results on thermal environment on Sunlighthouse.** The figure illustrate examples of results of enquiries though the four methods applied, respectively In-situ research, Blog, Questionnaire and Technical measurements.

## Air quality

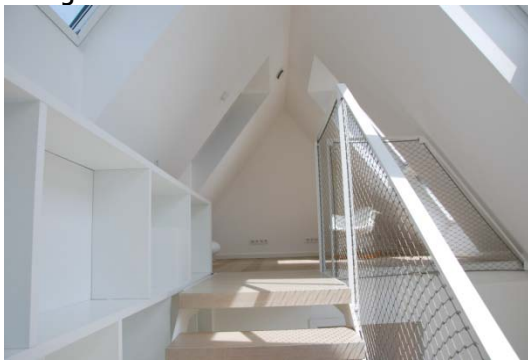

Air quality is in general perceived as very acceptable by occupants while measurements rate it lower. Especially in LichtAktiv Haus there is a long way between technical and perceived data as technical means of CO<sub>2</sub> are rated out of category by

the level being too high too much of the time (see. Figure 4(b) for criteria). In Maison Air et Lumière in-situ enquiries experience that air quality is not that good especially in traditional exhaust spaces such as bathrooms and kitchen, but also the bedroom is stuffy in the afternoon, despite an open door to the outside. Thereby the data different data

disagree and illustrate a wide representation of perspectives.

Another interesting aspect to the perceived air quality is that occupants instinctively relate this with health aspects and indicate they are feeling healthier; a sense reflected

across the blog. In Maison Air et Lumière the family describes this to have positive influence on quality of sleep, ability to concentrate when working at home, health in general and reduction in medication for asthma.

	LICHTAKTIVHAUS, Germany	MAISON AIRE ET LUMIÈRE, France
I N - S I T U  B L O G	<p><b>Rating: II</b></p>  <p>The tall staircase space is surrounded by roof windows in both roof surfaces to provide for airing and screening off where most appropriate.</p>	<p><b>Rating: II</b></p> 
	<p><b>Rating: I</b></p> <p><i>"Always fresh air through the automatic ventilation of the window, many hours of daylight in any room, large windows as well as open and spacious rooms in the house, which also produce enough energy for itself. This is our brave new world of living." Christian, 13<sup>th</sup> July 2012</i></p> <p><i>In recent days, we quickly realized how pleasant it is to have an automatic control of ventilation with natural air flow and the importance of independently operating shading in the different rooms. The air seems to us again now much fresher. The room temperature is better and we now have a neutral smell in the house... (...) It's very interesting how quickly we have grown accustomed to the automatics and involved it in our daily lives.</i></p>	<p><b>Rating: I</b></p> <p><i>"What we immediately experienced is that it's like having a "breathable house" as soon as you enter. My son and I are very sensitive to pollution and poor indoor air quality. We could really feel the difference compared to our previous home. (...) Rayan, who is asthmatic, often needed to inhale Ventolin after intense efforts on bike. Here, he uses his bike as soon as the weather permits: he descends and ascends the slopes and around the forest without needing medication now." 12<sup>th</sup> September 2012</i></p> <p><i>"We were already convinced that the fresh air and heating of the house does not only heat the interior but keep it healthy too. We can now confirm that it really works!" 20<sup>th</sup> October 2012</i></p>

Christian, 12th June 2012

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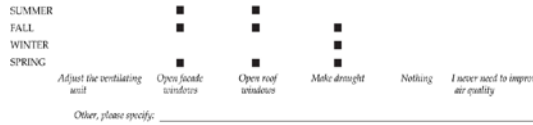
How have you experienced the air quality in the house during the last couple of weeks?



Have you experienced any problems with the air quality being...



What do you usually do if you want to improve the air quality?



Rating: I

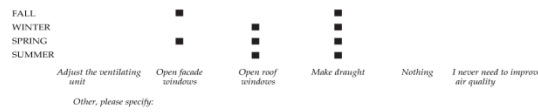
How have you experienced the air quality in the house during the last couple of weeks?



Have you experienced any problems with the air quality being...



What do you usually do if you want to improve the air quality?

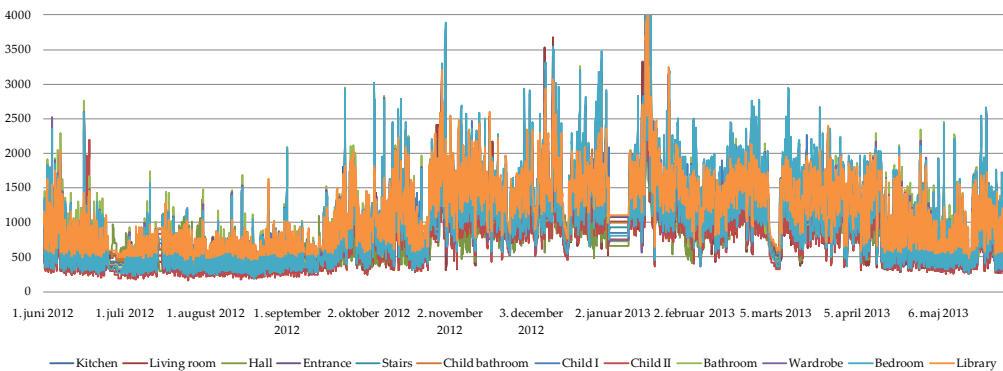


Rating: II

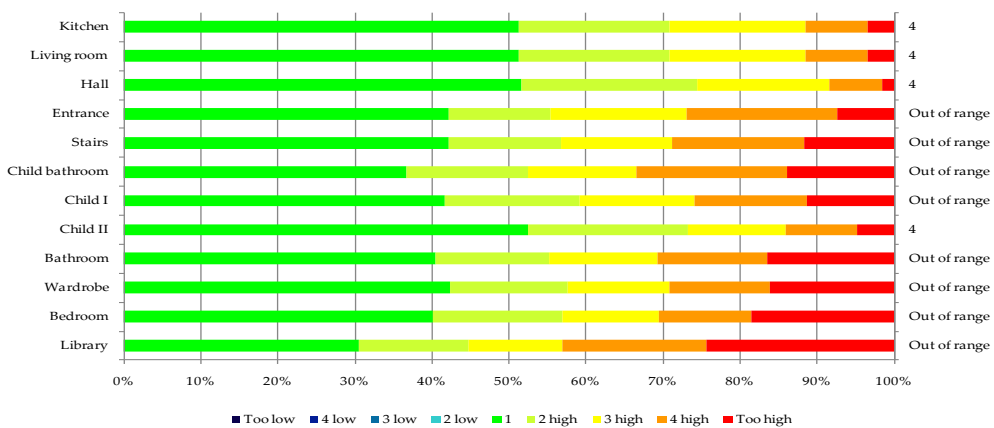
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LichtAktiv Haus | Rating: V

LichtAktiv Haus | CO2 | June 2012 - May 2013

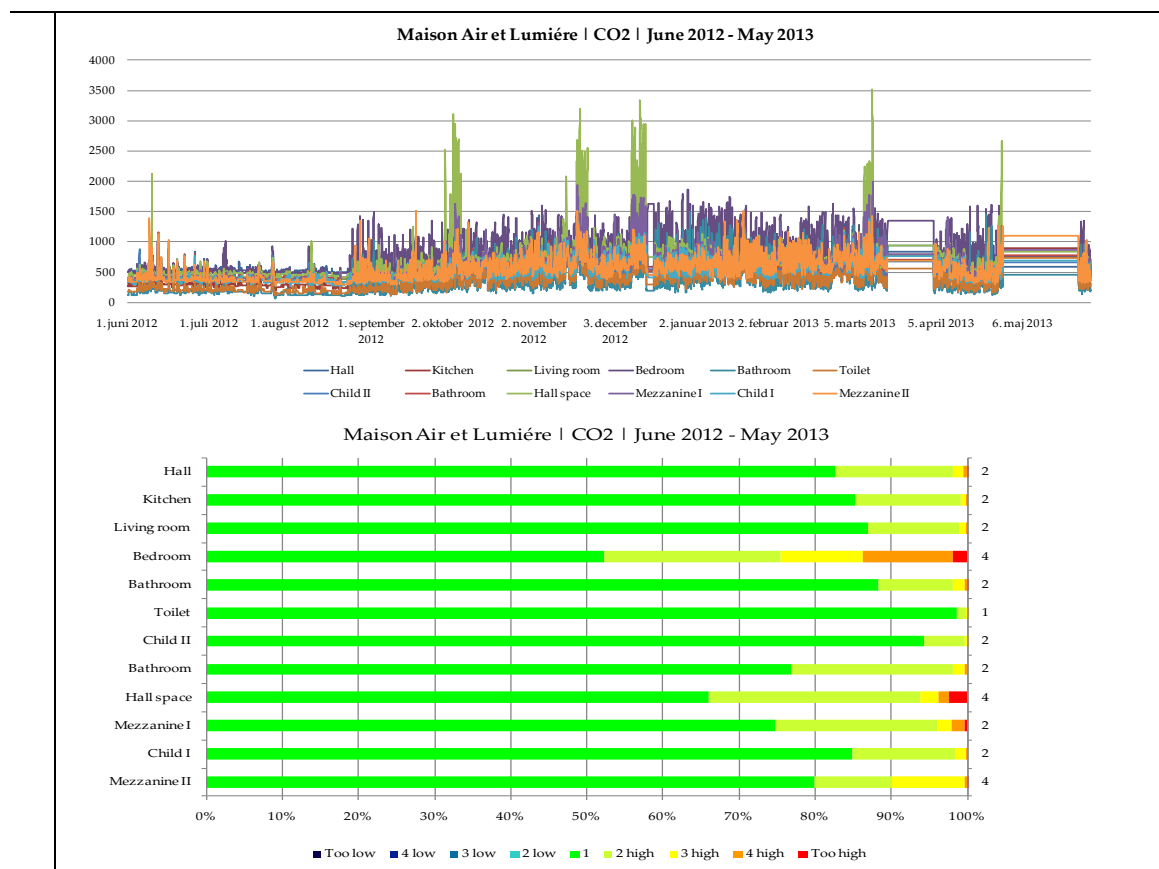


LichtAktiv Haus | CO2 | June 2012 - May 2013



Maison Air et Lumière | Rating: II









**Figure 6. Results on enquiry of Air Quality.** Illustrated through examples of results of enquiries through the four methods applied, respectively In-situ research, Blog, Questionnaire and Technical measurements from respectively LichtAktiv Haus and Maison Air et Lumière.

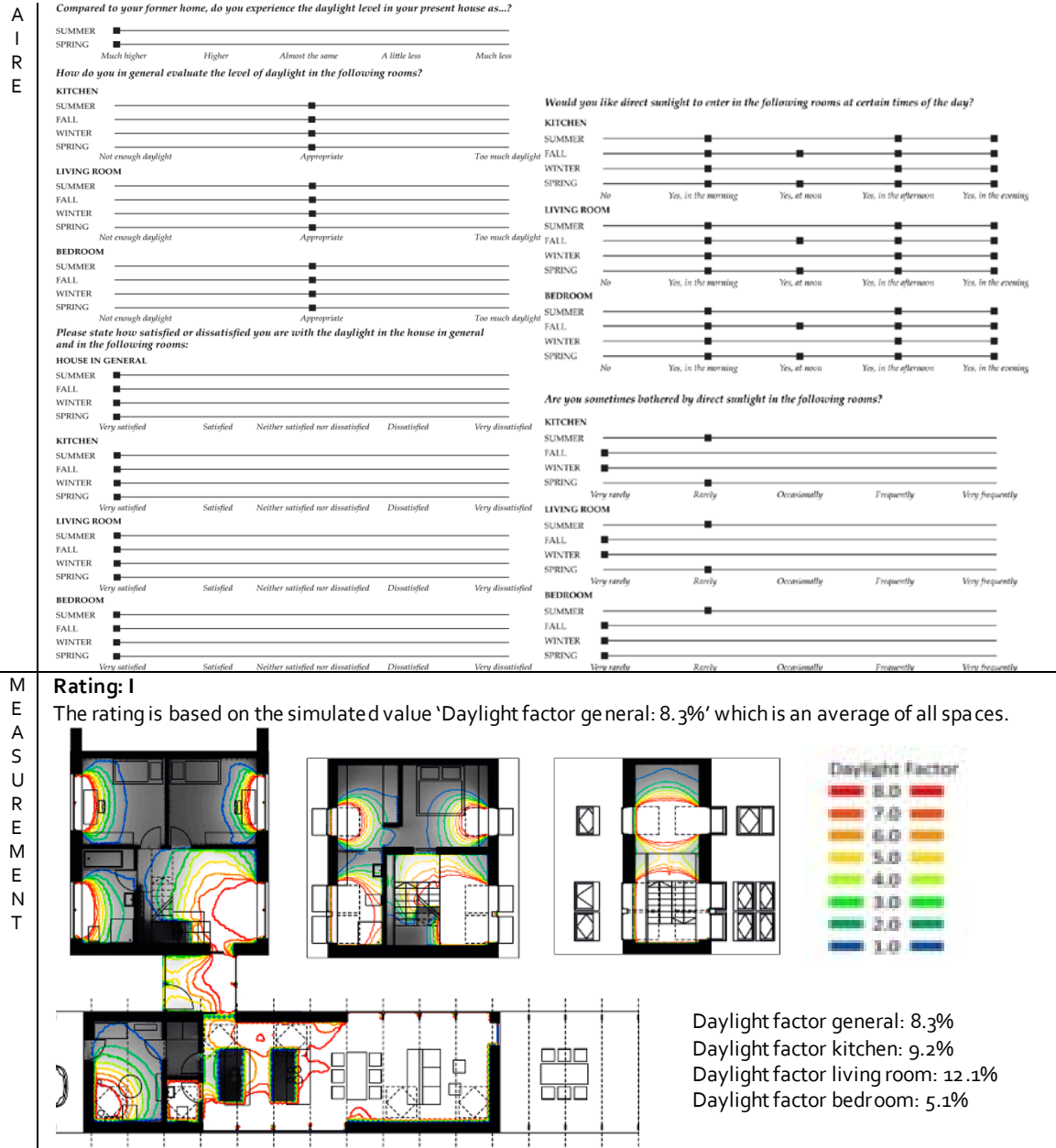
## Daylight

The light quality and brightness of the houses is very high; a common finding to all houses by all methods. The houses are designed and shaped to optimize daylight gains through day and year and this seemingly works well. This through design for distribution of daylight causes a few issues with keeping the light out during night time in Sunlighthouse, children's rooms facing southwest and Maison Air et

Lumière facing south. Here, light is important to take care of when designing or by using internal blinds. On the other hand availability of light is high; creating beautiful light spaces and also cause for reduction of energy consumption as electrical lighting is simply turned on less as tendencies show through measurements, usually not until after sunset or before sunrise and very much appreciated by the inhabitants. Filtering of light and temporality aspects are differently treated in each houses provide different

experiences but accentuation of this aspect spaces.  
really adds to the perceived quality of

	LICHTAKTIV HAUS, Germany			
I N - S I T U	Rating: I			
		Daylight is lead into the house in a variety of different ways creating for good distribution and beautiful, bright spaces.	Morning light through the tall facade windows in the living room/kitchen space create long shadows travelling on the walls.	 The staircase space creates a special feeling of light. Tall space roofed by windows, shadow play in the steel grid and bright space.
B L O G	Rating: I			
		"No artificial light in the day! It's great that the evening light is so long, thus we come out from breakfast until long after dinner without artificial light, a great feeling. That was unthinkable in the old apartment." Occupant, 3rd April 2013	"Bright, open, spacious, comfortable and of course energy efficient. Such is the time for us living in the Velux LichtAktiv from home. And we are very satisfied! Always fresh air through the automatic ventilation of the window, many hours of daylight as in any room large windows have been created, as well as open and spacious of rooms in the house, which do produce enough of their own energy. This is our brave new world of living." Christian, 13th July 2012	
Q U E S T I O N N	Rating: I			









**Figure 7. Results on Daylight.** Illustrated through examples of results of enquiries through the four methods applied, respectively In-situ research, Blog, Questionnaire and Technical measurements from Licht Aktiv Haus.

## View

The three houses represent three different kinds of view; in LichtAktiv Haus a near and intimate view into the private garden; in Sunlighthouse a long view over the lakes, mountain and woods of Vienna; and finally Maison Air et Lumière with a view of city roofs. Both blog and questionnaire reveal that view is perceived as very important or quite important to the occupants and especially views with natural characteristics are appreciated (blog). Views to nature and ability to follow change over hour, day and year is through all blogs accentuated as creating 'a good morning', 'quite

atmosphere', 'perfect place', and 'enjoy seasons' (see figure 8).

In case of Maison Air et Lumière level of satisfaction with the view drops through the year of enquiry; first the occupants are in general satisfied, in the second and third round they are neither satisfied nor dissatisfied, and though the fourth, they are dissatisfied. Neither questionnaire or blog poses any answers to this change in opinion; not until in-situ studies discover, a large house is being constructed to the south taking some view and create view in.

	<i>LICHTAKTIV HAUS, Germany</i>	<i>SUNLIGHTHOUSE, Austria</i>	<i>MAISON AIRE ET LUMIÈRE, France</i>
I N - S I T U	<p><b>Rating: II</b></p>  <p>Large windows in the kitchen provides for a near relation to the outside private garden – nearness to nature.</p>	<p><b>Rating: I</b></p>  <p>The large lovers-nest seat in the living room provides for a nice place with a breathtaking long view of mountains and lakes.</p>	<p><b>Rating: II</b></p>  <p>The view from the kitchen up on the road in front of the house is not inspiring, and to the garden side the view from the living room is being blocked by a new house.</p>
B L O G	<p><b>Rating: I</b></p>  <p>"Sun, blue sky and plenty of natural light for breakfast, that makes a good morning!" 22<sup>nd</sup> March 2013</p>	<p><b>Rating: I</b></p>  <p>"For me the panoramic windows the best seat in the house. The beautiful view of the Vienna Woods and the quiet atmosphere make this the perfect place for doing a little work or reading or just think about this or that alone." 23<sup>rd</sup> April 2012</p>	<p><b>Rating: I</b></p>  <p>"Autumn makes its mark: the days decrease and we can enjoy the light until dusk. We can see that we turn our lights about half an hour after our neighbours, the time to enjoy the orange colours of the season." 22<sup>nd</sup> October 2012</p>
Q U E S T I O N N A I R E	<p><b>LichtAktiv Haus   Rating: I</b></p>		

**How important do you think that the view through the windows is?**



**State how satisfied or dissatisfied you are with the view through the windows in the house in general and in the following rooms**

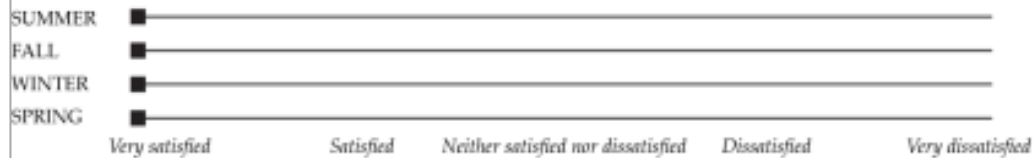
**HOUSE IN GENERAL**



**KITCHEN**



**LIVING ROOM**



**BEDROOM**



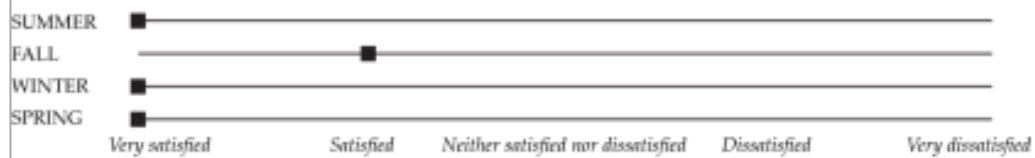
Sunlighthouse | Rating: II

**How important do you think that the view through the windows is?**

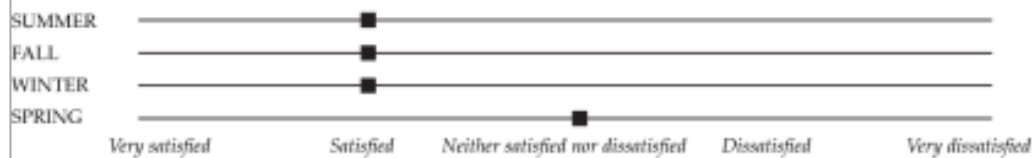


**State how satisfied or dissatisfied you are with the view through the windows in the house in general and in the following rooms**

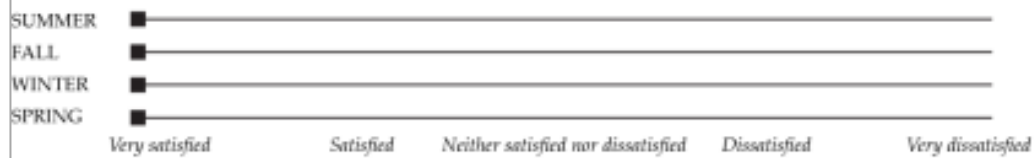
**HOUSE IN GENERAL**



**KITCHEN**



**LIVING ROOM**

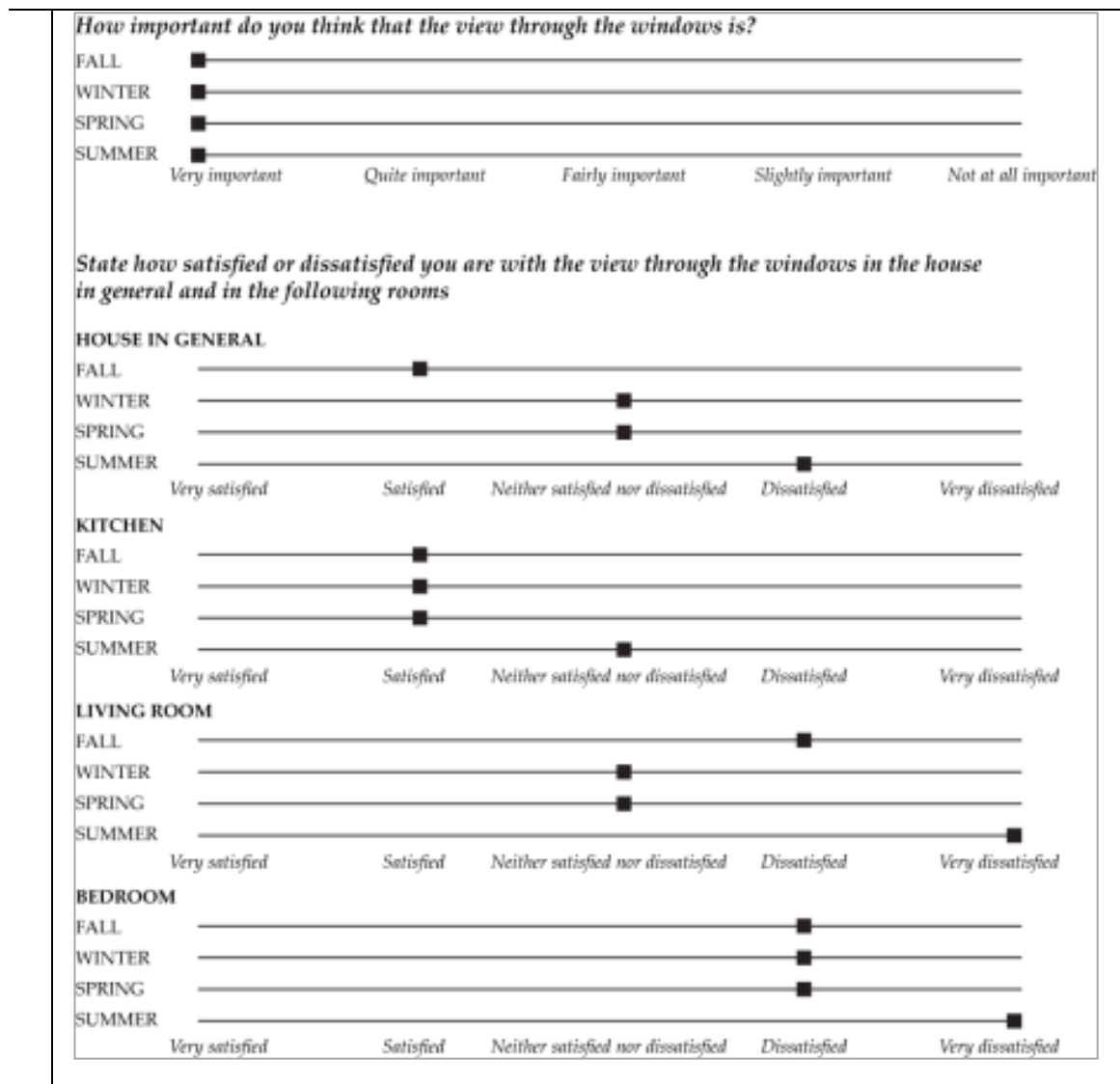


**BEDROOM**



**Maison Air et Lumière | Rating: III**





**figure8. Results on View.** Data on view are presented on all three homes. Their views have different characteristics and provide for different experiences for the occupants.

## Dissemination and diagram

Below, in Figure an example of results on one of the houses enquired in presented to illustrate the use and intent of the proposed dissemination diagram. Ratings are based on

a scale from I to V (where I is best) described through figure 4(a-b).

### LichtAktiv Haus

Figure 10 illustrate the perceived indoor environment in LichtAktiv Haus is generally

rated good and very good through the four methods; as resembling categories one and two. One aspect which is found problematic is that measurements provide such different results from the other methods in enquiry of air quality. This relation is a central point in this model for enquiry, as this illustrates that enquiry by technical measurement alone, or by any one aspect alone, will not provide a fulfilling illustration of the circumstances. The thermal comfort in the house is very good or good throughout the year, and the house seemingly manages to prevent overheating and heat loss when required to maintain the quality of the thermal environment, by means of natural ventilation to the joy and comfort of the occupants.

### Sunlighthouse

Perceived indoor environment in Sunlighthouse is generally rated in category II reflecting a good quality. The thermal environment is rated I with measurements as well as occupant perspectives which all indicate that the construction is good at keeping the temperature at a steady level. Perceived air quality is experienced by occupants as very acceptable or acceptable though the year and they do not experience and problems. Nocturnal ventilation and bouncy effect are accentuated by occupants as contributing to maintaining high quality. Measurements, however, disagree and rate air quality in category III – which is average. The daylight in the house is rated in category I through in-situ and questionnaire studies;

while blog and measurements rate this slightly lower in category II. This lower rating is an expression that the house lacks ability to create complete darkness and thereby occasionally might disturb sleep quality, especially during summer. The view from the house is rated very high in all categories, however questionnaire survey show difference in satisfaction with the view.

### Maison Air et Lumière

Perceived indoor environment in Maison Air et Lumière and generally rates the house in good in category II. The general picture across the themes of indoor environment is that the blog quotes are interpreted a category better than the remaining methods does – maybe due to its positive tone? The thermal environment in the house shows a nice distribution in measurement while questionnaire data varies slightly. The air quality is perceived by the occupants through blogs to have a positive effect to the health of the family causing a reduction of medication. Also, the blog puts focus to that transition periods affect the experience of air in the house. The house is designed so that bedrooms are placed to the south and west facades making them very bright and difficult to screen off dark at night during summer. Kitchen and living room spaces are drawn back from the façade and are perceived as a bit darker rooms; during In-situ studies it is experienced that occupants turned on electrical lights in the kitchen during daytime (June) and drew the curtains.

The view in the house is of suburb roof-tops, and is blocked by a house which is under construction as the in-situ studies are carried out. This steals off more view, and causes the occupants to be 'dissatisfied' and 'very dissatisfied' as reflected through questionnaire.

## General point

In general all houses are placed above average in their ratings indicating good quality of indoor environment. This responds well with the fact that the houses are developed as experiment projects with great attention to indoor environmental aspects and aesthetics.

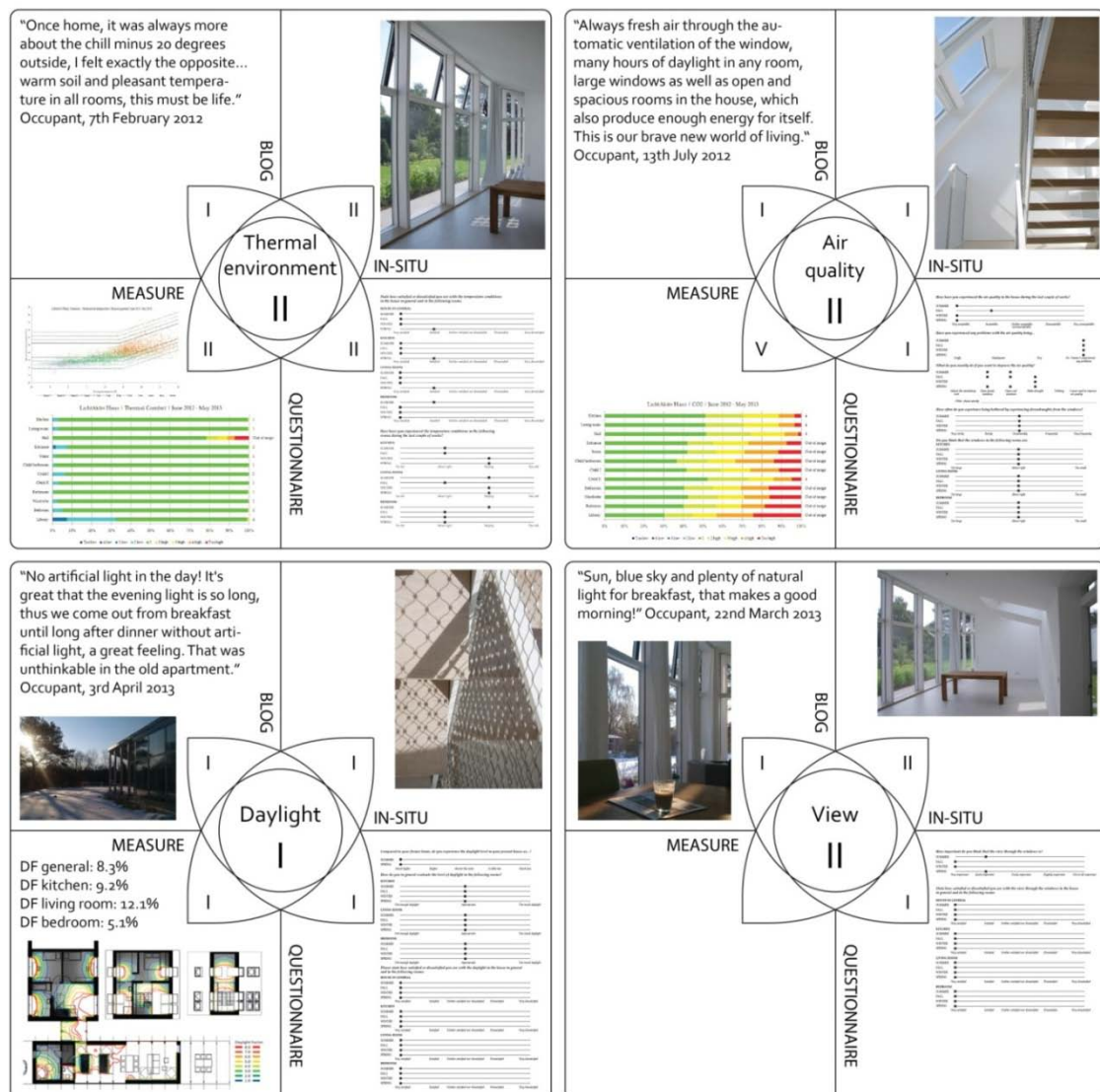


Figure 9. Results dissemination diagram of LichtAktiv Haus, Germany.

## Discussion

Discussion will focus respectively results of assessment through the designed model of enquiry and on strengths, weaknesses and perspectives to the model. Further, discussion will reflect generalization and validity of the proposed model.

### Challenges at a basic level

The field of sustainable architecture is facing challenges at a basic level. Often, engineers lead decision making processes, as they are commonly believed to have the better (technical) arguments on sustainability. Thus, what about other aspects of buildings - the functional, physical, physiological, perceptual and sensuous aspects? How can qualitative aspects be included in assessment of buildings on equal footing with aspects of technical ability? What about aspects of user perspectives – the users who live in the homes every day? How can dynamic aspects of this behaviour be included, so enquiry models will be able to create more complete illustrations of the actual circumstances for a sustainable life? What are the possibilities for holistic assessment with regards to practice and making valuation more approachable on several levels? These are some of the questions development of the proposed model is based on. Challenges are plenty. The above reflections will be touched upon through the following discussion. Figure 10 is used to frame the model in relation to ability and rating.

### Findings through the model of enquiry

The main idea behind the proposed model of enquiry is to create a framework that enables illuminating different aspects, themes, of sustainable life-form from a range of different perspectives and thereby covering quantitative, mixed and qualitative means to create a more complete understanding.

#### Thermal environment

The houses all generally perform well with regards to thermal environment and all methods rate them well above average. The theme of 'thermal comfort' it was possible to enquire through all four methods used. Additionally, all methods agree on the generally high quality of the thermal environment. This shows that the model is very able to enquire thermal environment, disregarding whether results are good or bad. Maybe this is due to the approachability of the theme – it is easy to have an opinion about if a space is too hot, comfortable or too cold. It is also easy to measure temperature – and it is measured in a unit commonly used every day in home thermometers, the oven, and freezer or fridge.

#### Air quality

Something a bit more intangible is air quality. Normally, units such as ppm and % are not shown in homes and people do not encounter these every day in the same way they do temperature. Thus, the air quality of the homes is one of the things occupants'

blog the most about; illustrating they are aware of it and show ability to reflect it and put words to it. This becomes even more evident when visiting the houses as they have a generally nice feeling of fresh air and nice/fresh scent.

One thing that catches the eye through the enquiry results are, however, that where the air quality is measured to be too high with a rating outside the scale, the perceived experience show that occupants are very satisfied (LAH). It is thereby relevant to point to that equipment might be good enough or be calibrated wrongfully? Or technical rating demands might be too tough? Active House vision [25] suggests demands on air quality in homes based on EN 15251 [16] which do not make specification for homes. This may be a place to make further enquiry as to explore if air quality rating should be as in the workplace or school or if these are even necessary at home? A hall way in the evening after being warmed by direct sun all day; a bedroom with two grownups sleeping in though the night; or the kitchen after hours of cooking for several guests results in higher CO<sub>2</sub>. This is like any houses – determined by level and type of activity, thus the measurement equipment in these houses captures these fluctuation and thereby point attention to them.

### **Daylight & View**

This is a theme which showed great strengths in enquiry through several different methods. This clearly shows that daylight has been of central consideration through design and development phases.

The houses showcase many creative solutions to integrating many windows in the building shell, and really utilise the roof as a fifth facade – for both daylight and energy gains. Daylight is integrated into the designs rather than being merely a bi-product of having windows. This way of making a virtue of necessity is a model example for future houses. Not only because these houses showcase a range of possibilities in making such solutions but mainly as these show that the design are created with intelligent and insight. Variability in light angle, time of day, how it is desired to draw light into the space at a specific time of day, and similar elements such as that are considered through the design. Therefore, all methods rate daylight conditions very high in all houses.

Experiencing the light in these houses, its characteristic variability when moving around the spaces truly creates a feeling of something sustainable. A feeling of wanting to explore and follow these movements of light and narratives of shadows every day. This is an element of true sustainable nature.

An aspect where the houses do not perform as well is in creating darkness. As people

need plenty of light and brightness during day to be well, they need real darkness and sound sleep at night as well. Darkness could and should be explored more in the design solution of these houses. The solutions for light at day are brilliantly successful – those for screening off could possibly be as well.

View is an interesting aspect in these houses. One might think – what does view have to do with sustainable living? Well, enquiries through this work have shown that it does have quite a lot to do with it. All occupants state though questionnaires that view is a central aspect to them. Families more satisfied (continuously) (LAH and SLH) are also the families that have the most amazing views according to in-situ studies.

Visual privacy is an aspect connected with integration of windows and creation of view. Studies of similar houses showed that occupants can be very bothered by people gazing in at them from the outside through the large glassed areas. This problem has not been brought up as an issue by the occupants in these three houses, while in-situ studies did, however show that the issue exists on a lower level in SLH while to a wider extent in MAL.

### **Acoustics**

Sounds and acoustics is an interesting theme in relation to architecture. Sounds are present in surroundings all the time and people use sounds to perceive, notice, navigate and much more. Often, they are not even noticed.

Experiences from In-situ research studies drew the attention to the influence of sounds on the environment created. Traffic noise, silent buzzing sounds of nature, quietness, a 'bbbrrrrrrrr' from a motor on a window; all impressions captured through these studies. It is a special feeling being woken up by a loud 'klik' and a bbbrrrrrrr' from a window; chock and annoyance... and then a feeling of a soft breeze of fresh air. However, acoustics were not really in focus during the enquiry in general as no measurements were made on this. Therefore, the theme is also difficult to reflect on and assess, as only snapshots are captured though respectively blog posts and questionnaire. Thus, it is a common conception from in-situ research, blog and questionnaire that the noises of windows opening and closing suddenly cause annoyance and sometimes scare.

### **Pursuing a thematic approach**

Rather than focusing on strict methodological approaches this approach focus on common subjects of interest. Thereby, it suggests a break down in the divide between different scientific knowledge fields by considering themes of interest central and then applies the methods best applicable to explore the matter or theme of interest. This provides possibility to disregard a certain knowledge field and thereby just pick the methods best applicable to make the illustration best possible. It is relevant to discuss whether the model

succeeds to doing so and also identify shortcomings.

Of the 25 elements selected for enquiry through this work, only five of these could be answered by all four methods. This is an interesting fact which support the very foundation of the work; namely that application of only one, or a few, methods is hazardous as it is not immediately possible to see through what the methods does not measure.

### Dynamic elements of enquiry

Usually, assessment is performed pre-construction and dynamic variables are disregarded to a wide extent. But, the life that unfolds in a house, the passing of second, hour, day, season and year are all dynamics. With ongoing development of intelligent systematic solutions to controlling and adapting exterior and interior environments of buildings, time has run out for stationary assessment approaches. They are no longer able to capture complexities of sustainability which is not merely a matter of technical ability, but also of functional, physical, physiological, perceptual and sensuous performance. Thereby, need for dynamics and multifaceted assessment approaches emerge as it is relevant and necessary include variability in assessment of buildings in-use.

This paper differs from previous research by approaching to capture complexity of homes

and users through a dynamic, integral mixed methods approach. The aim is to create a model for assessment of sustainable homes which is directed at practice; that include aspects of perceived quality on the same level as technical ability, include user perspectives and is based on dynamic means to comply best possibly with development of sustainable architecture.

### Model findings

Exploring the proposed model through empirical cases and data proved valuable to identifying what aspects the model and its methods are able to tell something about. Figure 8 represents an assessment of what methods were able to answer to the different aspects of the selected themes. For instance

One problem the approach faces is the problem of average. The dissemination diagram illustrates an average value based on the four ratings. This is a treacherous cause and might suppress important knowledge and hide the range of a category one and four respectively in an average rating II.

### Generalisation and validity

Carrying through the research on three cases is a rather modest quantity which not automatically forms the foundation for talking about statistical significance in the findings. However, due to the character of the study, it is relevant to discuss aspects of generalisation. Three houses represent a



good percentage of the number of Model Home 2020 houses built in total, and the findings from these houses for sure are valuable to the remainder of the type. Also other Net Zero Energy buildings could gain from the knowledge acquired through these studies, creating a sound base of knowledge within the field.

## New aspects to this method

This method differs from its predecessors on a range of aspects including:

- The method considers content rather than approach and thereby moves away from focusing solely on one knowledge field.
- Introduces assessment of perceived quality.
- Introduces double perspective on occupant experiences by combining questionnaire with the new blog approach.
- Introduces an aspect of variability by collecting data over (longer) time.

## Conclusion

This work proposes a model for enquiry of sustainable homes. This model is developed and empirically tested through this work through aspects of indoor environmental aspects.

The model is able to enquire five aspects of indoor environment out of the 25 explored through all four methods. The remaining aspects are all enquired by one method or more.

Thermal environment, air quality and daylight are well illuminated through the model for enquiry, while aspects of view and visual privacy are not that well illustrated yet found basic. Acoustics and sounds are hardly enquired and ratable by the model – an aspect which should be explored and developed further.

The model for enquiry of sustainable homes is able to provide a more complete illumination of the main portion of aspects of indoor environment; and the model do provide a more thorough illustration than either of the methods would alone.



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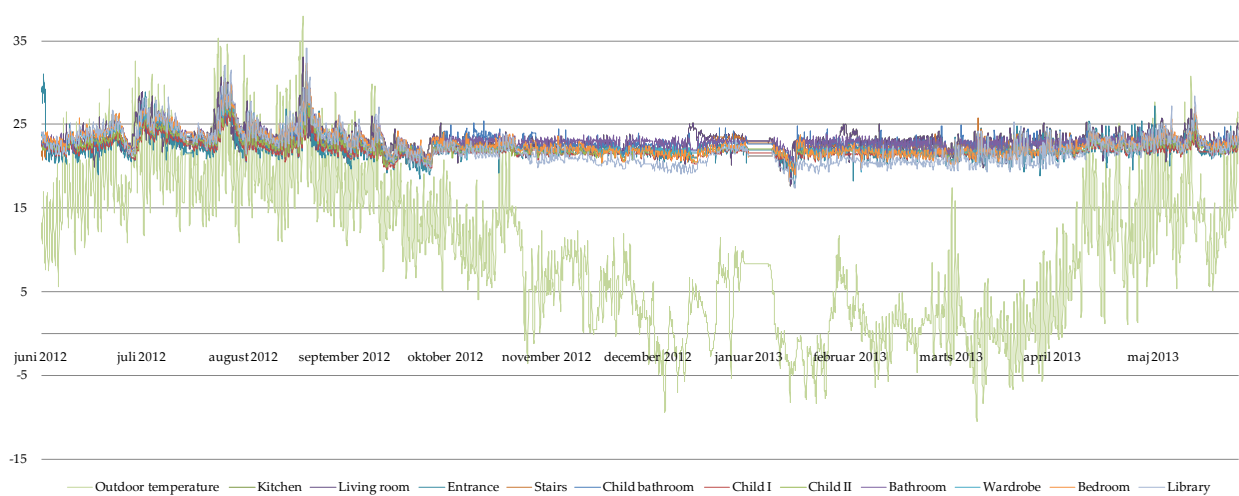
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## Enlarged illustrations

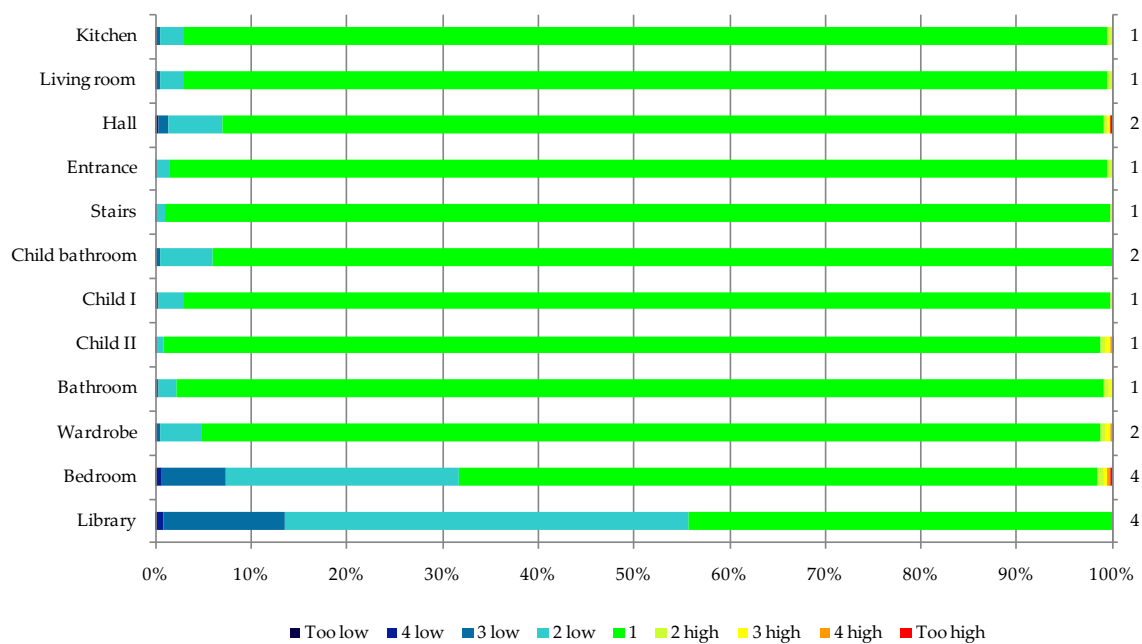
### LichtAktiv Haus – Results of technical measurement data collection, treatment and rating on Indoor Environment

#### Thermal environment

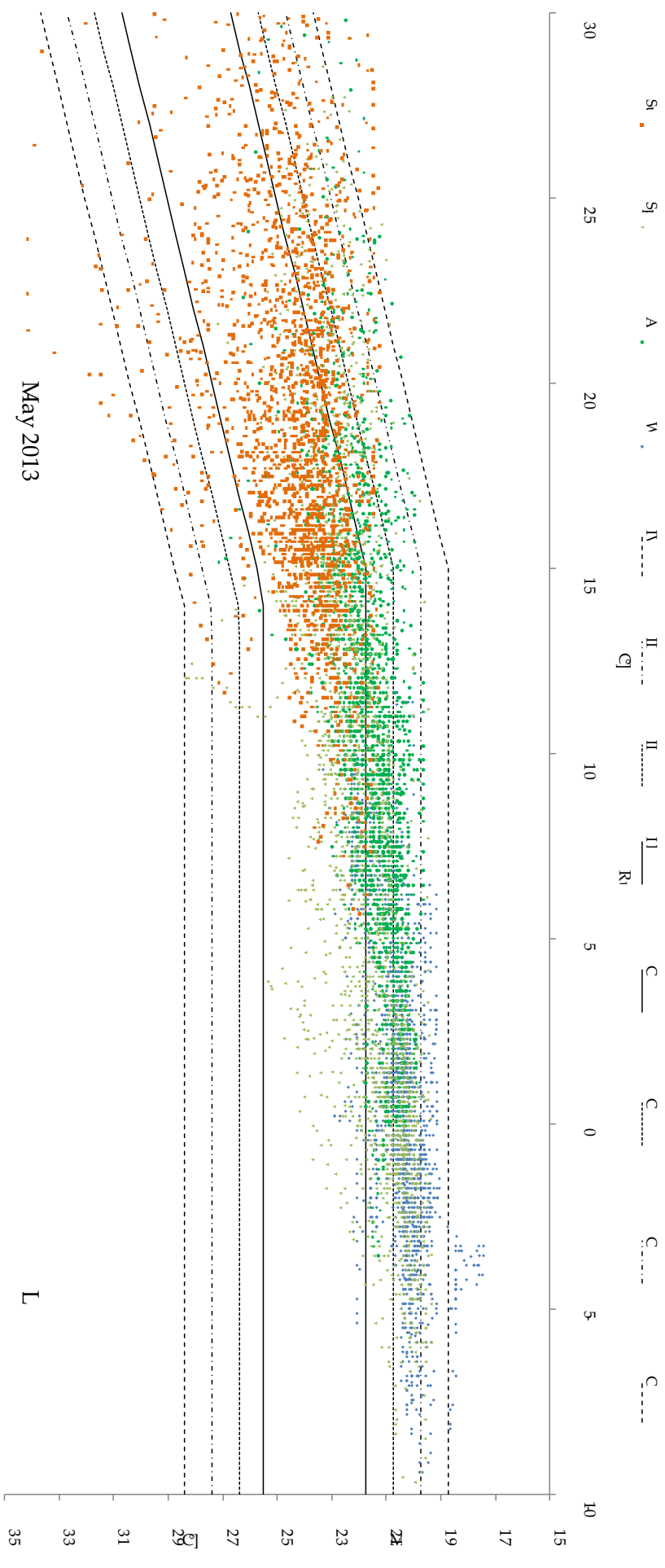
LichtAktiv Haus | Measured indoor and outdoor temperature | June 2012 - August 2012



LichtAktiv Haus | Thermal Comfort | June 2012 - May 2013

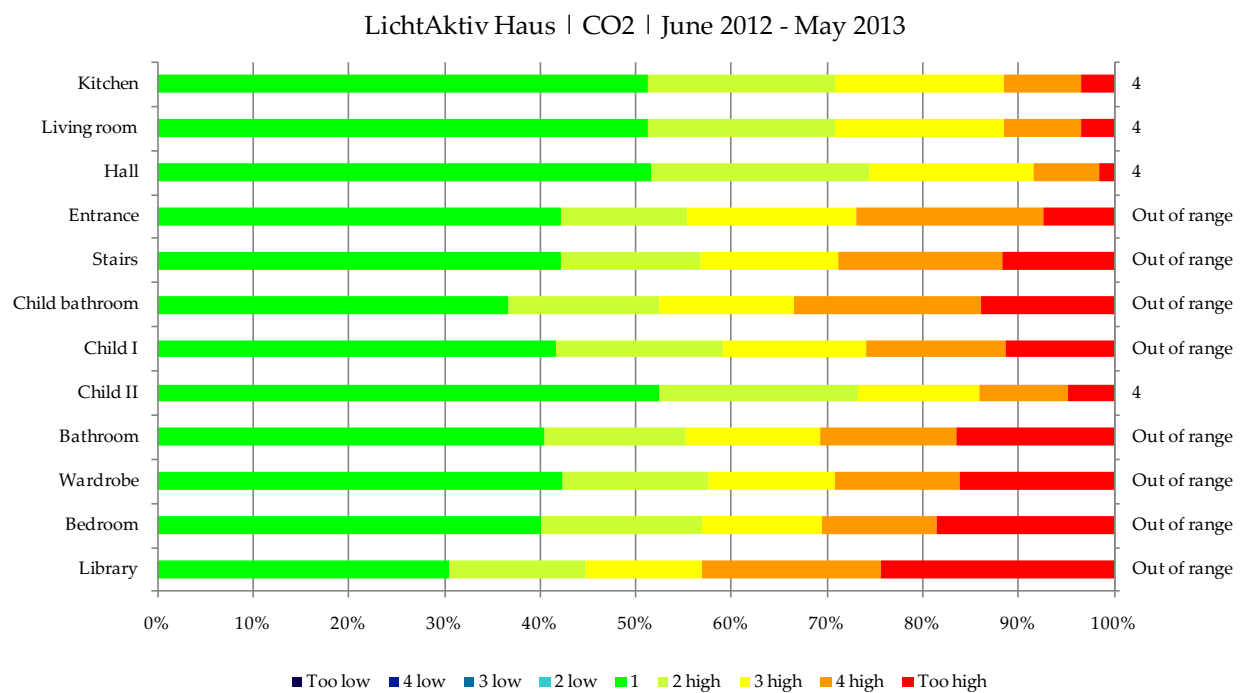
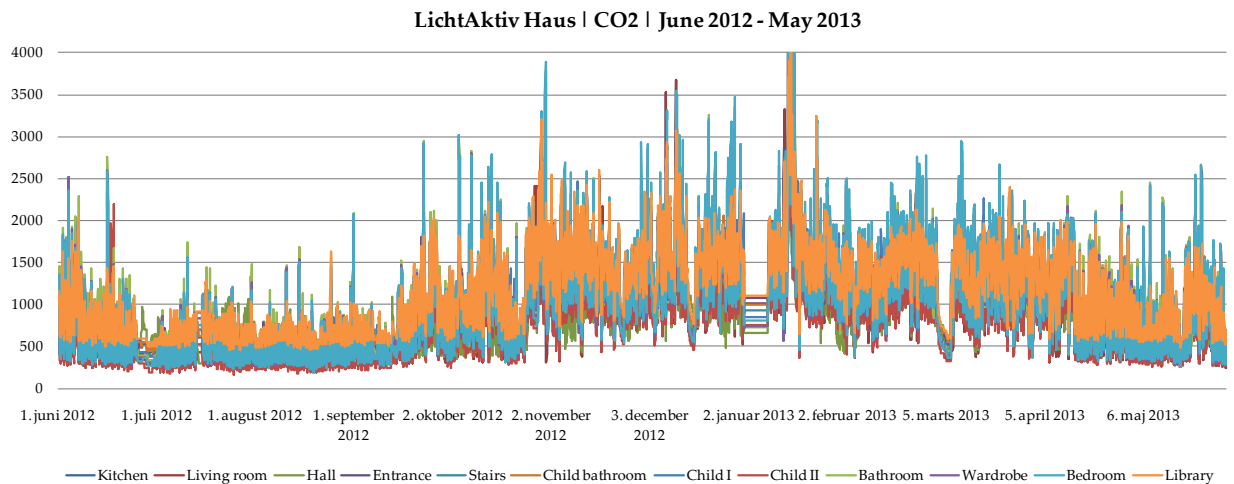




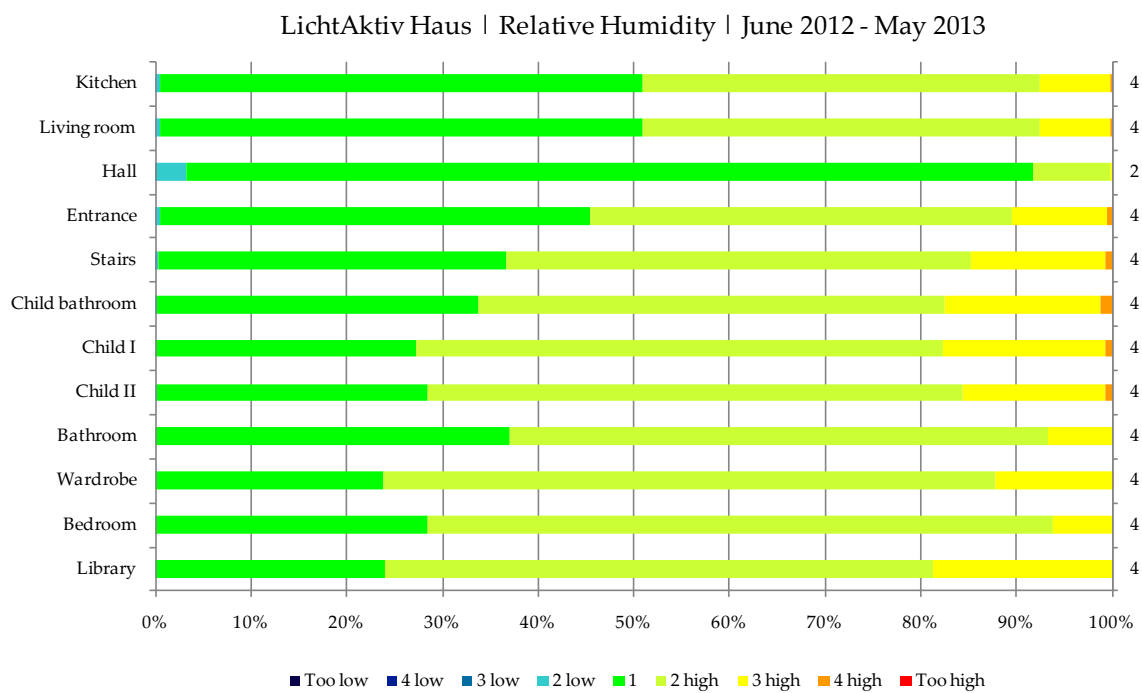
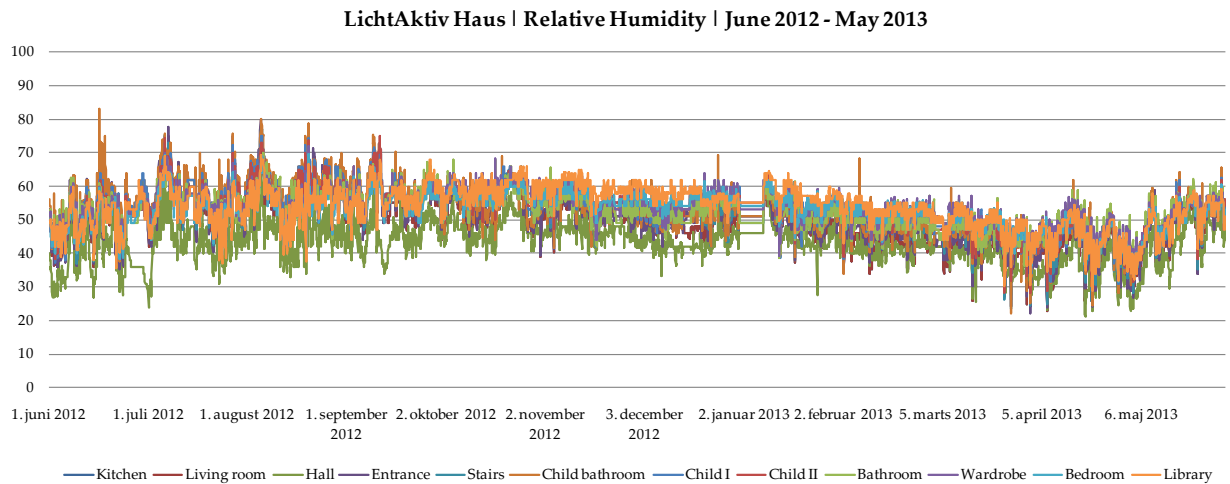


## Indoor Air Quality

### CO<sub>2</sub> levels



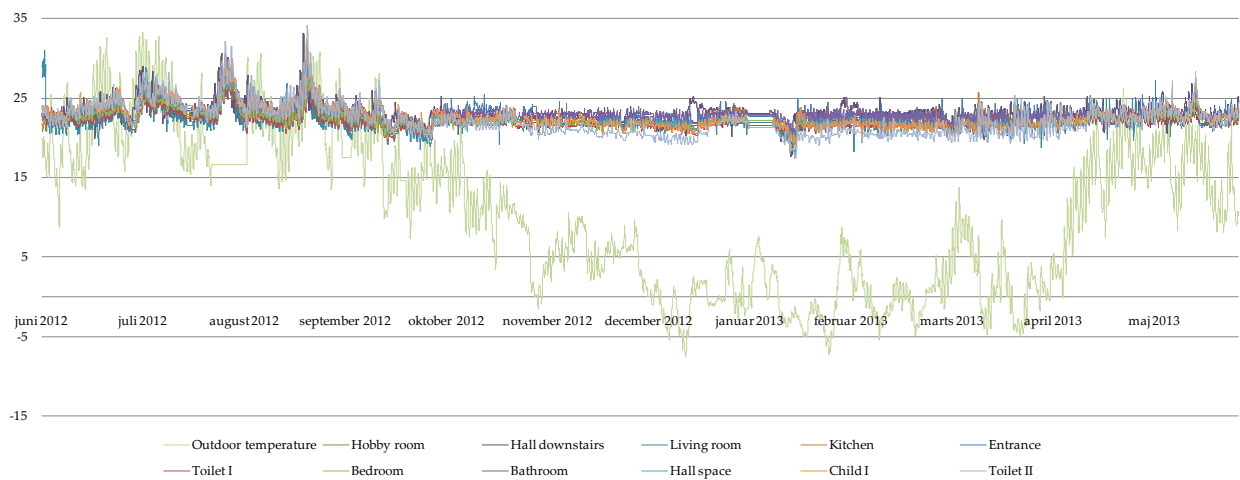
## Relative Humidity - Year



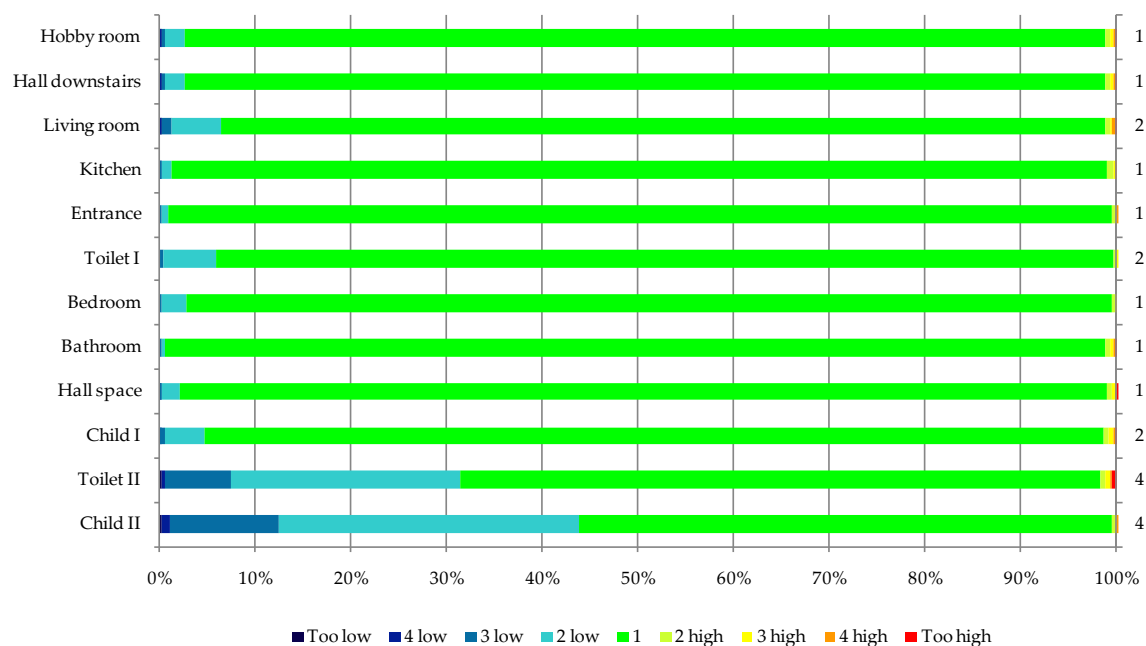
# Sunlighthouse – Results of technical measurement data collection, treatment and rating on Indoor Environment

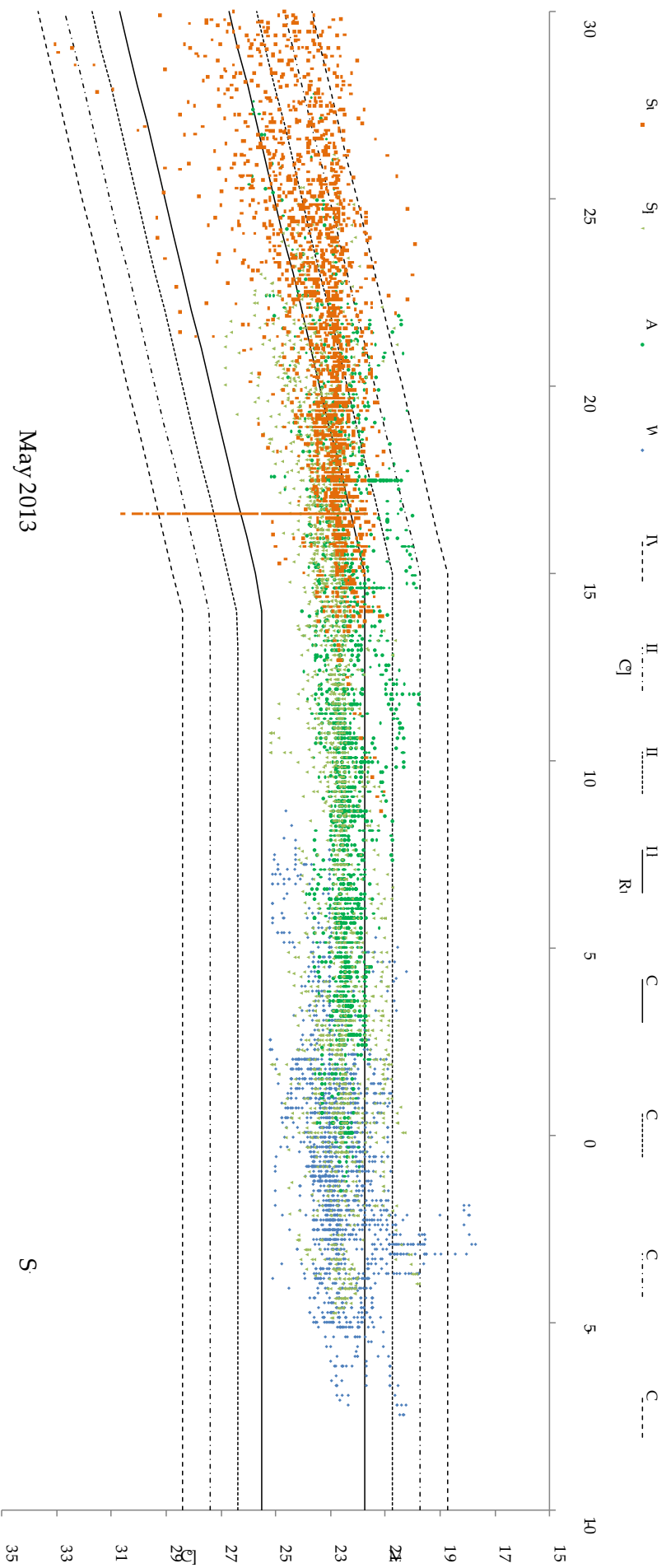
## Thermal environment

Sunlighthouse | Measured indoor and outdoor temperature | June 2012 - May 2013



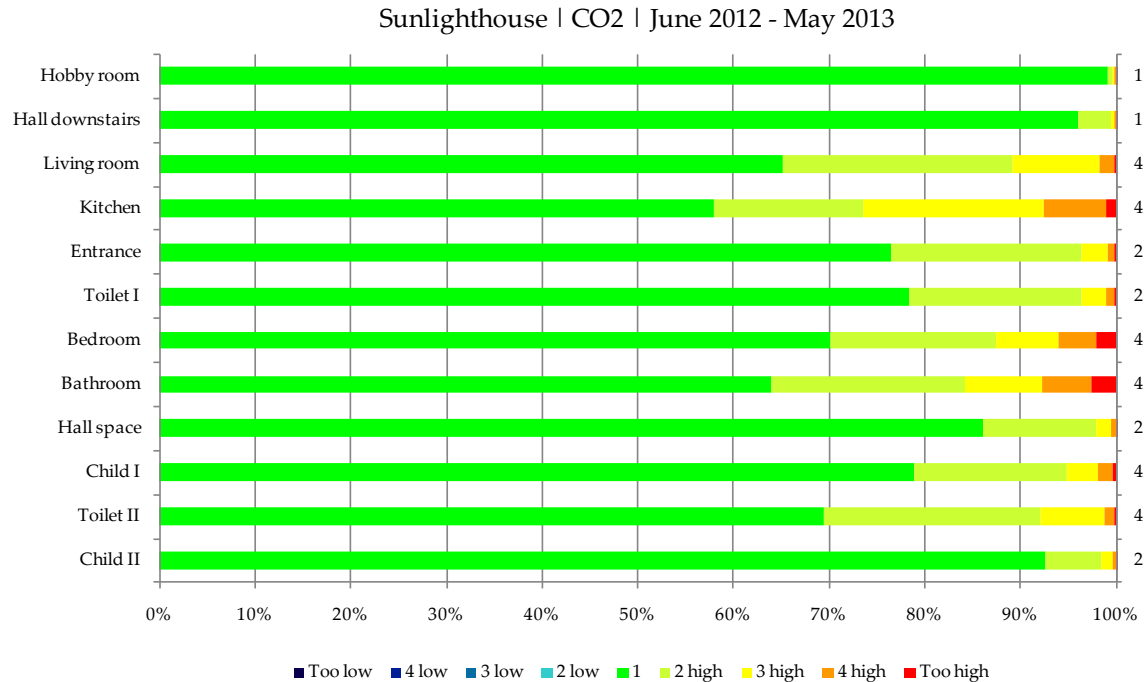
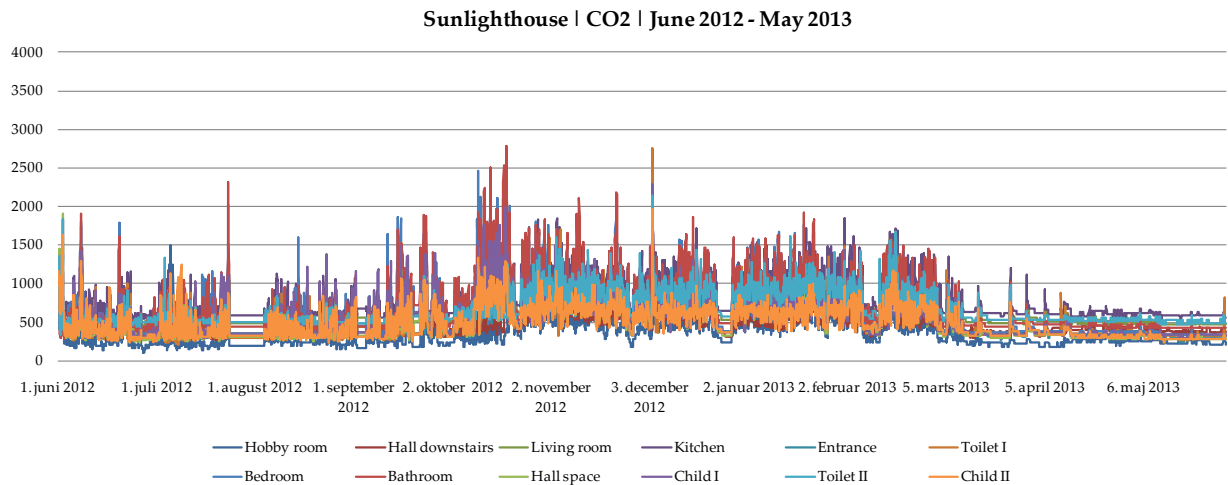
Sunlighthosue | Thermal Comfort | June 2012 - May 2013



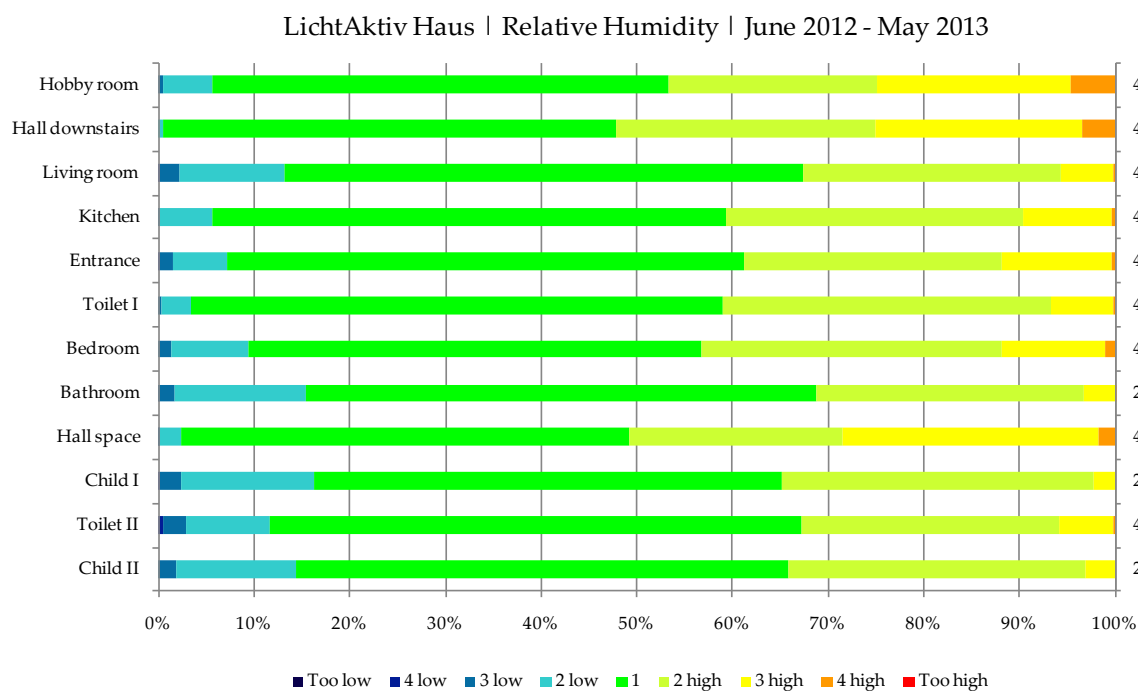
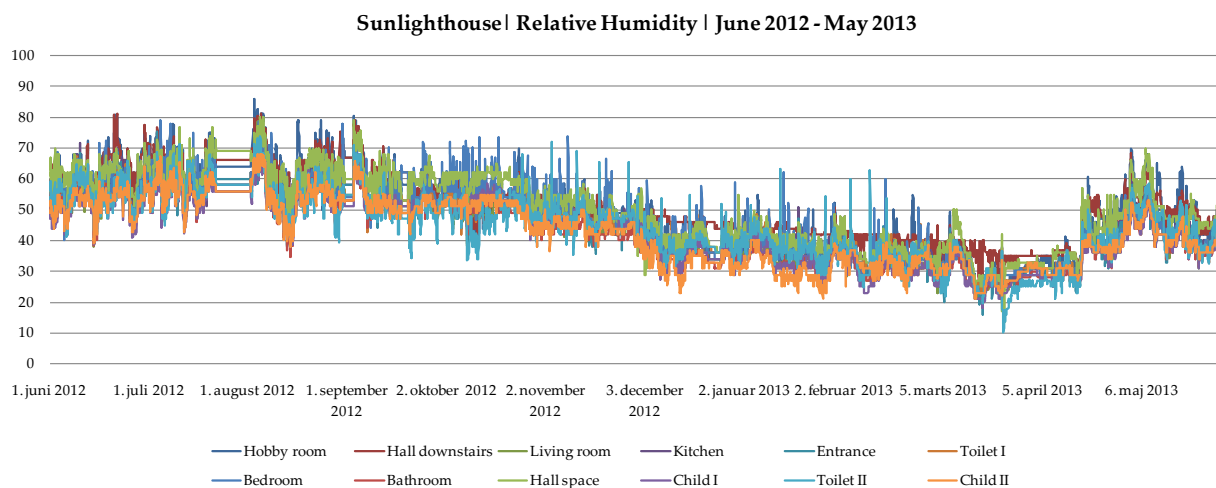


## Indoor Air Quality

### CO2 levels



## Relative humidity

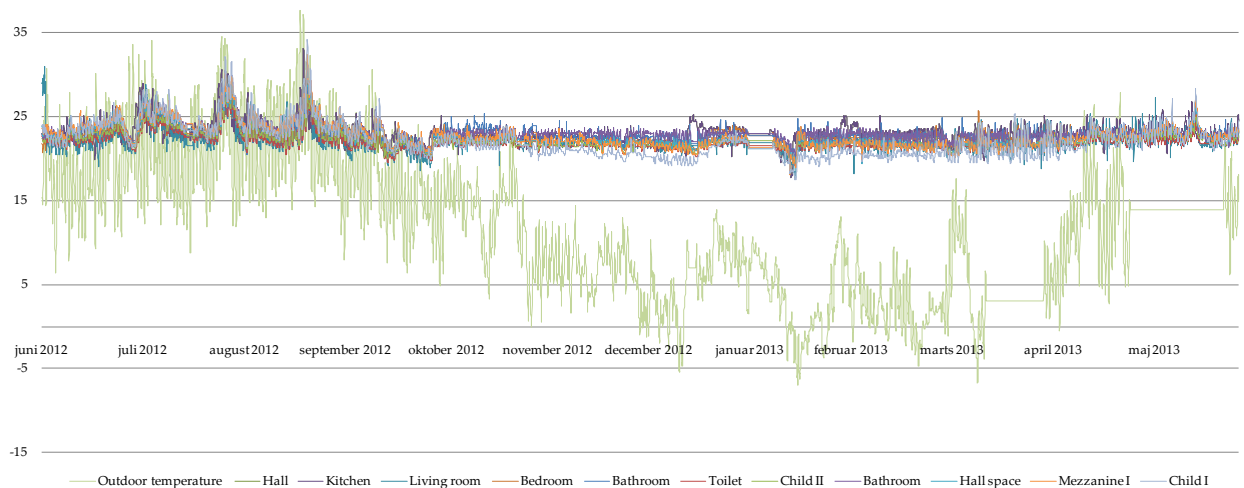




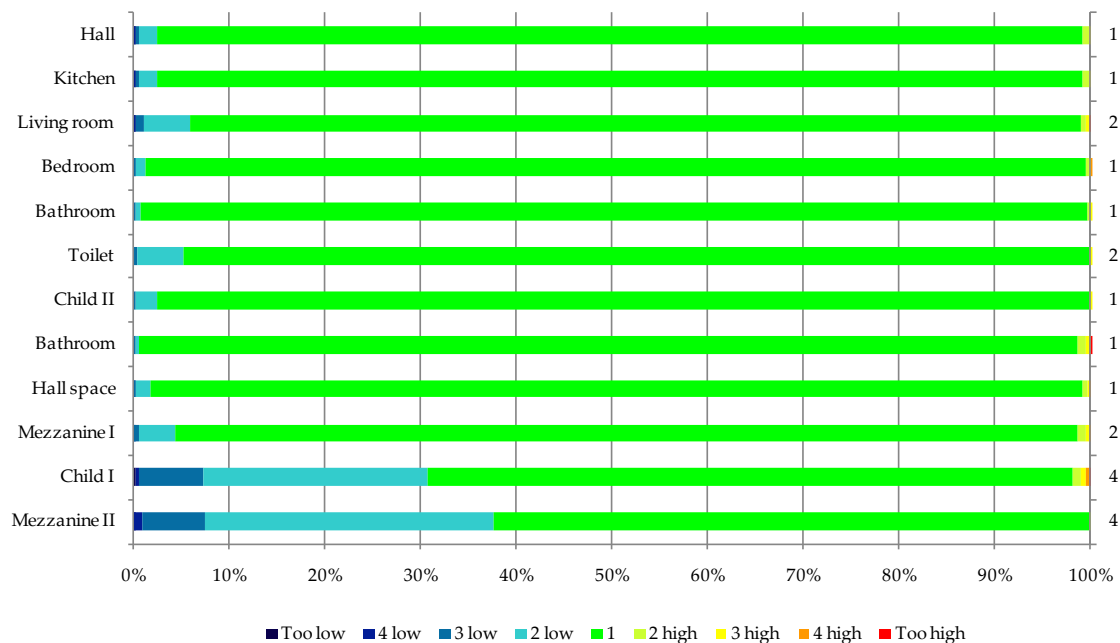
# Maison Air et Lumière – Results of technical measurement data collection, treatment and rating on Indoor Environment

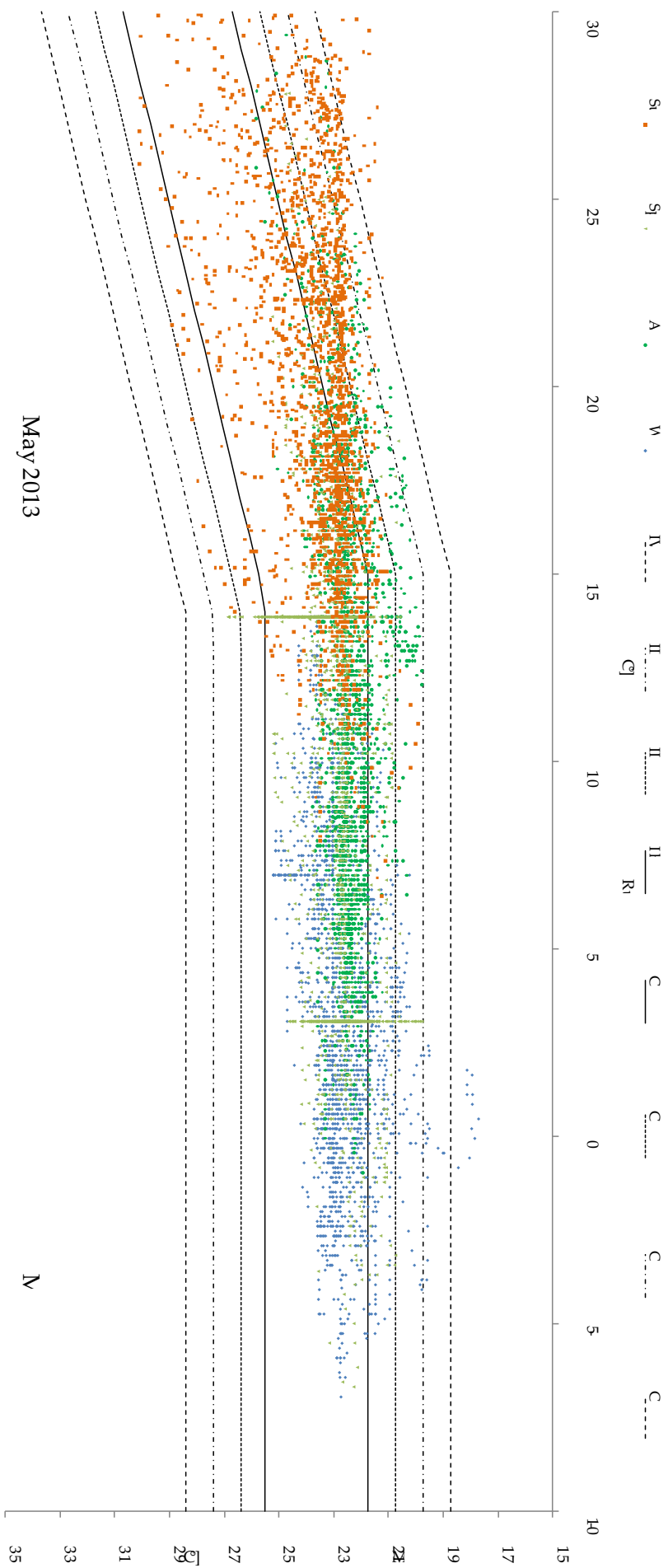
## Thermal environment

Maison Air et Lumière | Measured indoor and outdoor temperature | June 2012 - May 2013



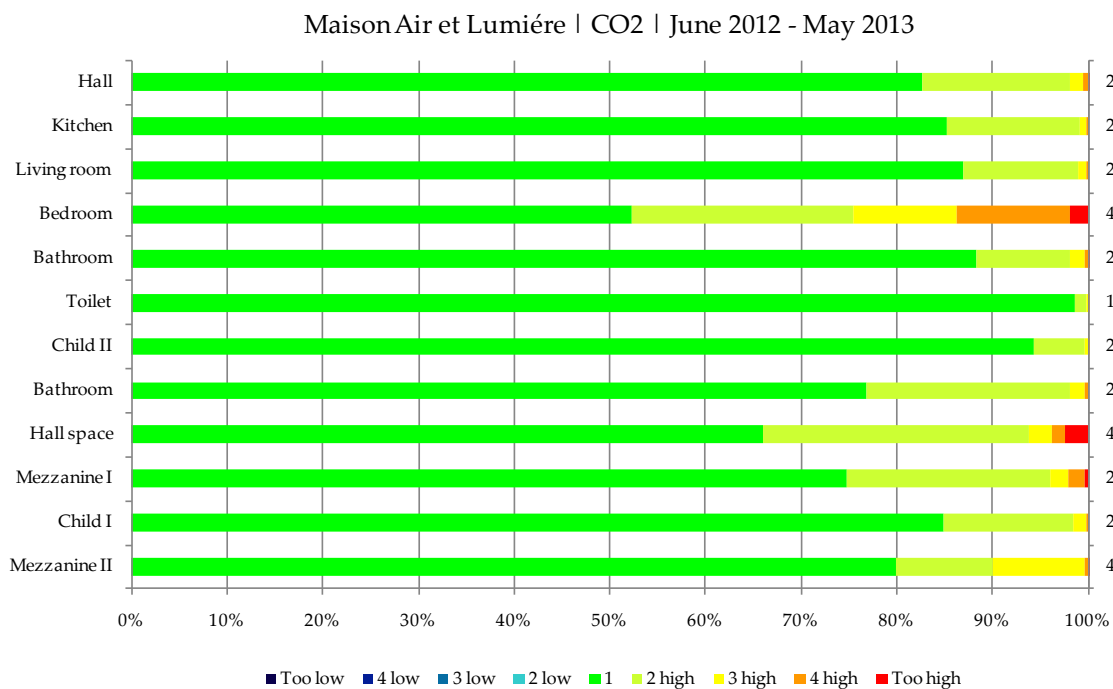
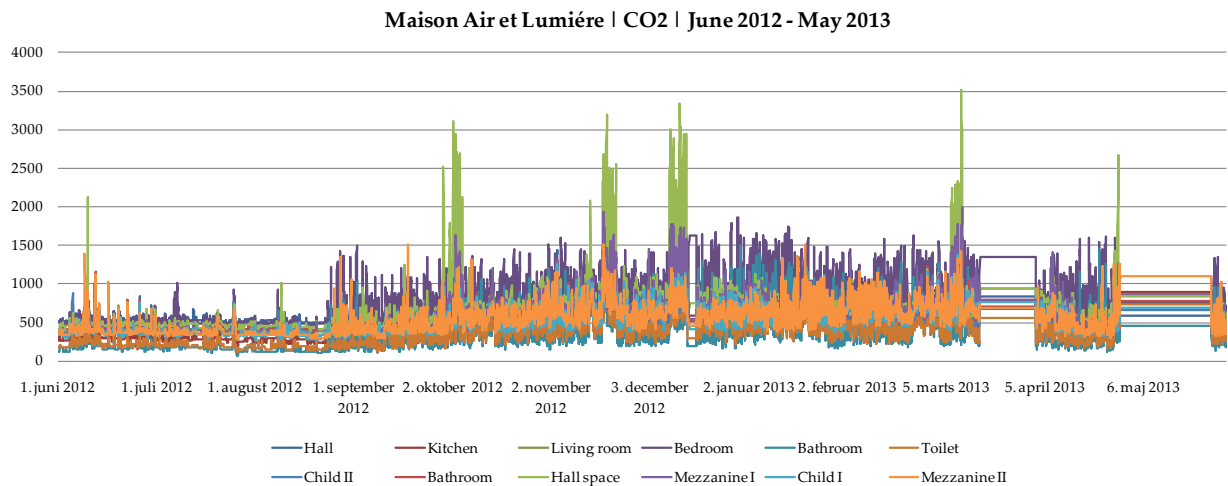
Maison Air et Lumière | Thermal Comfort | June 2012 - May 2013



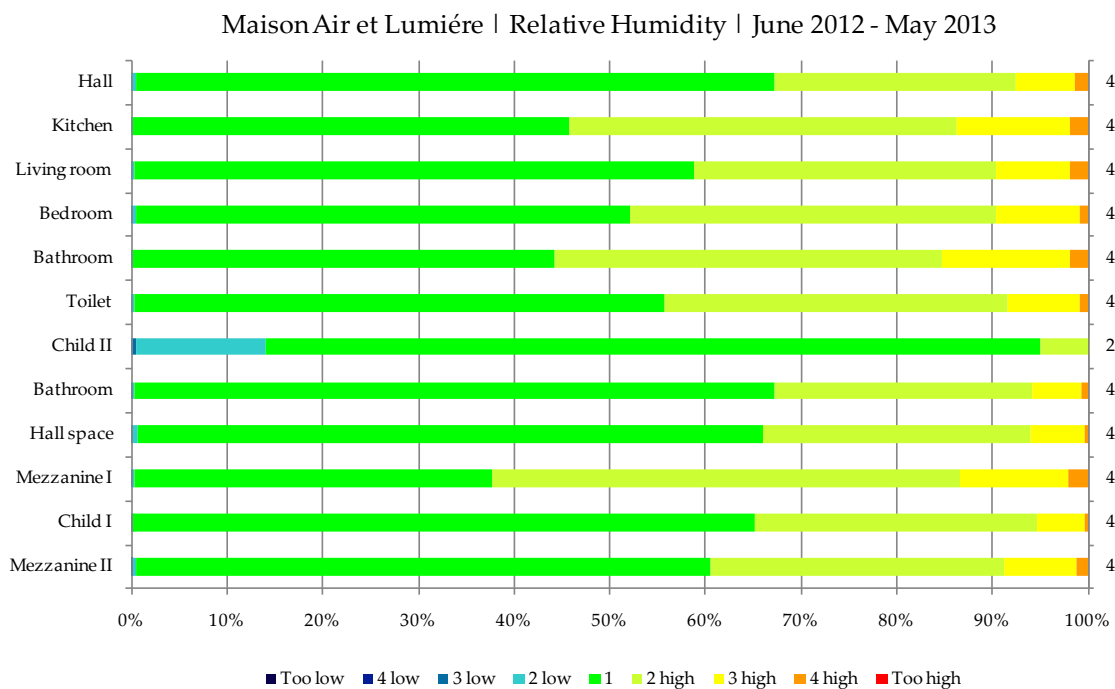
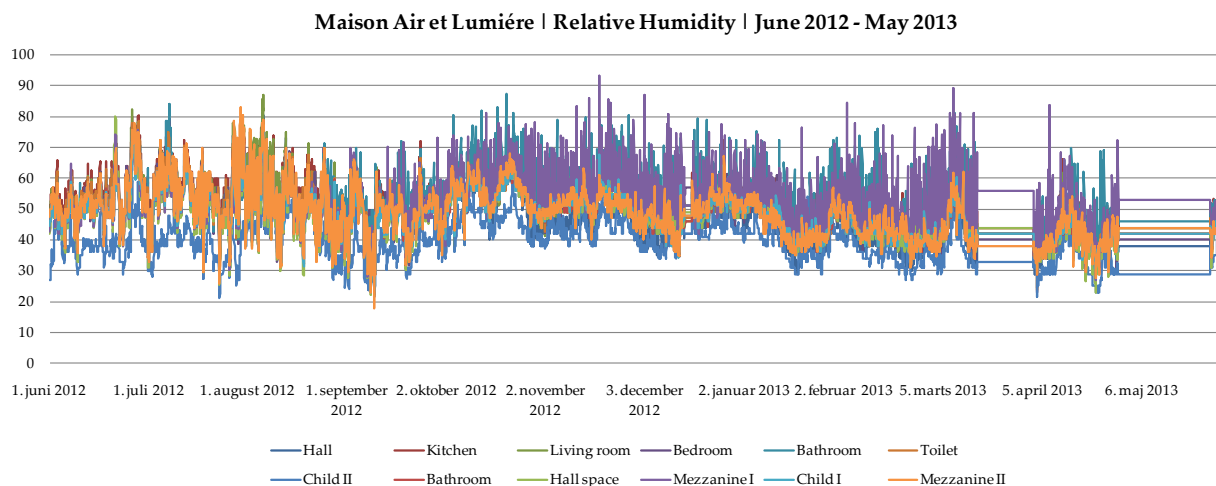


## Indoor Air Quality

### CO<sub>2</sub> level



## Relative humidity



***Encountering Sustainable Functionalism: Feedback as a Method to Raise Awareness on Energy Use and Indoor Environmental Aspects***

*Gitte Gylling Olesen, Mary-Ann Knudstrup, Per K. Heiselberg & Jens Christoffersen (2013)*

*Submitted to Architectural Science Review. Taylor & Francis Online*

# Encountering Sustainable Functionalism: Feedback as a Method to Raise Awareness on Energy Use and Indoor Environment in Automated Homes

*Automation solutions are becoming increasingly common within sustainable buildings and an interest in the relation and interaction between technology and the user blooms. The purpose of this enquiry is to explore occupant perspectives on this increasingly technologically based life-form. This is enquired through occupant encounters with automated systems. The article also shows how this effect occupant's view on aspects of energy uses and comfort. Explored in an empirically based multi methods setup the article enquires three automated homes and their occupants. Through questionnaire and blog approaches the aim is to create an illustration of occupant awareness on energy use and indoor environment. This is a part of a research project about developing a model for enquiry of sustainable homes. Conclusions are that successful encounters with automated homes depend on compliance with needs; occupants are not afraid of technology moving in; and that more technology is desired.*

Keywords: blog, feedback, home automation, questionnaire, sustainable functionalism

## Introduction

With the coming of the 2010s technologies for sustainable buildings are widely refined and an interest in the relation and interaction between technology and user blooms. (Braungart & McDonough 2009; Brunsgaard 2011; Entwistle 2010; Knudstrup, Hansen and Brunsgaard 2009; Olesen et al. 2010a; Aschehoug & Andresen 2008; Andresen et al. 2008) This relation is an expression of a human factor in sustainable architecture focusing on users' role in creating sustainable homes also bringing along dynamic aspects of ever-changing human needs and wishes. (Drexler and El khoulil 2012; Marsh, Grupe-Larsen and Hacker 2008; Olesen et al. 2011b; Steemers and Steane 2012; Janda 2011; Baird and Lechat 2009; Baird et al. 2008)

Currently 40 percent of the global energy consumption is used for constructing and running buildings and the main portion of energy is consumed by buildings in use. Different kinds of families use varying amounts of energy and research indicate user behaviour influence energy consumption in homes with 40-60 percent. (Brunsgaard 2011; Jensen 2009; Gram-Hanssen 2011; Gram-Hanssen, Kofod and Nærvig Petersen 2004) The main reason for energy consumption is to maintain indoor environments of a certain quality and comfort to the occupants. Thereby, in-use situations and user behaviour are central to determining actual sustainability of a building.

### State of the Art on automation and occupants

To comply with user needs so-called home automation systems are integrated to

automatically adjust indoor environmental conditions. For years, machines and automation managed comfort needs at work; now automation is also moving in at home (Bluyssen 2009; Edwards 2009; VELUX A/S 2013; Jensen 2009). With the increasing automation a shift in use of buildings is foreseeable. From being merely static floors, walls and roofs with windows and doors reacting to physical interaction; building components can now be 'intelligent' and automatically opened and closed. This programming does not automatically function in sync with user needs but with pre-programmed patterns. This is a challenging relation as these systems are introduced namely to comply with users needs. Hawkes points out that the neglect in including the human factor in automated control is due to the complexity it entails:

*'Until quite recently the theory and practice of environmental control in buildings did not take into account the nature of the voluntary responses of building occupants to the environmental conditions they experience. To some degree this neglect was a reflection of the complexity of the subject, but was also a consequence of the predominant view of the aims and methods of environmental control.'* (Hawkes 1996, 29)

Røpke et al. (2010) explore how Information and Communication Technology (ICT) (e.g. computer, Internet, Smartphone) that is increasingly infusing everyday life affect energy use in homes. They find that people increasingly integrate energy consuming practices in their behaviour, such as repeating checking Smartphones and having more computers, without explicit awareness that this increase energy use. User experiences are uncovered through in-depth qualitative interviews.

*Kanstrup and Christensen (2009) in their work on feedback motivated electricity consumption find transparency in feedback in central to motivation:*

*'(...) feedback, which motivates electricity conservation with the right information, at the right time and at the right place. Ecological feedback forms a backdrop of the habits related to consumption of electricity by being transparent but at the same time psychologically self-motivating by being reflective in the reminding at a glance in situations where a reminder is accepted.'*

The project 'Minimum Configuration, Home Automation' focus on exploring aspects of home automation through anthropological methods, participant observation and cultural probes. (Entwistle 2010) Projects on Home for Life and Energy Flex-house in Denmark are full scale approaches to exploring, among other aspects, automation in sustainable state-of-the-Art homes. Test families move in and their perspectives are captured through, mainly, qualitative semi-structured interviews. (Olesen et al. 2011a)

## Encounters between occupant and automation

Based on the increased focus on encounters between occupants the automation, it is central to explore and develop knowledge on how occupants experience living in and with automated homes. Can feedback from these automation systems increase occupants' awareness of energy use and indoor environment, which is a prerequisite for more energy efficient practices?

## Methods

This study is based on a mixed methods research design where approaches are integrated in a Concurrent Triangulation

Strategy where data sets are compared to determine convergence, difference or combination. (Bryman 2008; Creswell 2009) The research includes methods on respectively questionnaire and blog approaches.

As illuminated in the previous chapter, research on occupant encounters with automation in homes is commonly approached through applied methodology, often from social sciences such as sociology and anthropology (Entwistle 2010; Hastrup 2010a; Hastrup 2010b; Kvale and Brinkmann 2009). Often, these methods are used to explain technically measured data, with the purpose of providing an expanded understanding and their possible implications to the occupants. (Brunsgaard and Larsen 2010; Entwistle 2010; Larsen et al. 2010). Knowledge found through these approaches is valuable for illuminating occupant perspectives. Outcomes are often provided through quotes, conveying the message in a captivating manner.

With approaches from social sciences applied follow great workload. Design, execution, transcription, analysis and communication of observation or interview data are time demanding. In industry timely resources are valuable and cutting back hours equals economic gains. Therefore, this paper seeks to explore if the same kind of qualitative and captivating data can be collected otherwise, through a blog approach where the researcher resources are reduced and the occupants' resources enlarged.

## Questionnaire research

The most commonly used method to explore occupant experiences in the built environment is questionnaire research. The approach inherently quantifies, but then what about the



more qualitative and non-quantifiable aspects of occupant perspectives and might there be a lack of commonly validated questions in the diverse applications?

Questionnaires are designed on basis on previous enquiry in expectations to user preferences. Rating is based on the Likert scale in a three or five step range answering possibilities (Likert 1932).

Through this enquiry focus is mainly on aspects of encounter through consulting and operating the system and how automation complies with occupant needs – and thereby on encounter and feedback from automation. Data on energy climate and indoor environment are secondarily included to elaborate findings on system and automation as these reflect the consequences.

## Blog

The single-family test house Home for Life was occupied by two different families from 2009 to 2012 (Web a). Research projects on the house and families approached a new way of collecting occupant perspectives: though diaries. (Entwistle 2010; Web b; Web c) The first family prepared diaries on a quarterly basis (Simonsen 2010). The findings in these were found to be valuable to understanding life in the house, but also that data collection happened too rarely. The second family prepared diaries on monthly basis, a more suitable interval (Hansen, Olesen and Mullins 2013). An example from the second family's dairy expresses the narrative and seductive character of data this approach can offer:

*'It has been interesting to experience that the house reacts – in some cases it even feels like the house acts as a direct function of human needs. The solar*

*shading, for instance, closes just as we start to feel the need to rub our eyes and the skylight window curtains closes just before the sun breaks through the clouds. If one did not know better one might think that the house was connected with one's nerve system.'* (ibid)

A weakness to the format is the handling of files; however, the approach is rather time efficient compared to an interview approach.

This paper suggests and explores a blog format as substitute for the qualitative diary approach. Blog, also called web log, is "a personal website or web page on which an individual records opinions, links to other sites, etc. on a regular basis" (Oxford Dictionary). Thereby, this can be characterised as sort of an online diary expressing experiences on a regular basis. This is an interpretation shared by experienced blogger Julia Lahme 'A blog is place where you share: experiences, impressions, opinions, knowledge and possibilities' (Lahme 2013). Blogging has grown in recent years and it is a medium easy to use. It is increasingly often used in research maybe due to its informal character and accessibility? Examples of research based on blogging can be found in many fields of knowledge such as perceived relevance of tourism blogs (Chen, Shang and Li 2013) or blog-assisted learning in schools (Lin et al. 2013).

Within the field of sustainable buildings blogging provides a new opportunity to capture user experiences. The format is based on occupants own interest, time and effort and might possibly reduce workload of researchers significantly. Blogs are laid out as a free format for the occupants to fill in what their experiences and perspectives on life in the

houses are. There are no restrictions to what the occupants can blog about and they are encouraged to supplement their narratives with photos.

Quotes from blog presented through this work are translated from occupants' original language to English to the best ability of the authors, as all posts are written in occupants own languages to best possibly express themselves.

## Empirical enquiry

To explore the effect of feedback as a method to raise awareness on energy use and indoor environment the blog and questionnaire approaches are tested on three Model Home 2020 homes and their families. Collection of data is conducted in concurrent multilevel setup with individual sampling in a longitudinal process where data are collected during a period of one year (Bryman 2008; Boolsen 2006). Figure 2 provides an overview on data collection.

## Model Home 2020 and automation





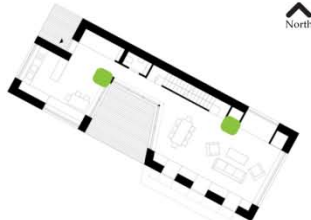










Three Model Homes 2020s houses LichtAktiv Haus (hereafter called LAH), (hereafter called

SLH) and Maison Air et Lumière in (hereafter called MAL) and their occupants are subjects to the research. Please see Figure 1 for characteristics of houses.

The idea behind the Model Home 2020 vision and approach is to combine excellent indoor environment with high quality homes mainly driven by renewable energy sources as contextually optimized design solutions (WEB). All houses have automatic systems installed as to optimize indoor environmental conditions, for instance by automatically opening and closing windows to air out exhaust air, pull down solar shading to prevent too much solar gains or close windows when raining. Sensors are installed in each house in each room about 1.60 meters about floor level. Sensors registered temperature, CO<sub>2</sub> and relative humidity levels to adjust indoor environment. A weather station is installed on the roof to register temperature, rain, global illuminance, hours of sunshine and wind direction; data also used to adjust. (Gylling et al. 2011b)

Data collection	LICHTAKTIV HAUS	SUNLIGHTHOUSE	MAISON AIR ET LUMIÈRE
Occupants	1st Dec. 2011 – 1st Dec. 2013	1st March 2012 – 28th Feb. 2013	1st Sep. 2012 – 31st Aug. 2013
Blog	1st Dec. 2011 – 31st May 2013	1st March 2012 – 28th Feb. 2013	1st Sep. 2012 – 31st May 2013
Questionnaire	12th Aug. 2012; 12th Nov 2012; 6th Feb. 2013; 7th April 2013	18th Aug. 2012; 13th Nov 2012; 12th Jan 2013; 20th April 2013	25th Oct 2012; 31st Jan 2013; 30th April 2013; 28th June 2013

**Figure 2. Data collection overview.** The figure display information on when different types of data collection is carried out. Questionnaire data are collected seasonally for each house while blog posts are collected continuously.

	<b>LICHTAKTIV HAUS (LAH)</b> Hamburg, Germany	<b>SUNLIGHTHOUSE (SLH)</b> Pressbaum, Austria	<b>MAISON AIR ET LUMIÈRE (MAL)</b> Verrieres-le-Buisson, France
Photos of the houses on blogs by occupants			
Main floor plan (Green dots indicate where monitors are placed)			
Description	<i>Renovated doublehouse + addition</i>	<i>New-built single-family</i>	<i>New-built single-family</i>
Size m <sup>2</sup> brut/net	189 m <sup>2</sup> / 132 m <sup>2</sup>	304 m <sup>2</sup> / 201 m <sup>2</sup>	234 m <sup>2</sup> / 173 m <sup>2</sup>
Floors	3 (old) / 1 (new)	3	2 (+ 1/2)
Test families	<i>Family Oldendorf Christian (40), Irina (38), Lasse (9), Finn (7)</i>	<i>Family Dorfsetter Ludvig (32), Yasmin (30), Alfred (4), Johann (2)</i>	<i>Family Pastour Fabrice (38), Samantha (29), Ryan (8), Ishmael (4)</i>
NV Comfort			
Visualization MWa Touch			
Weather station			

**Figure 1. Characteristics of houses.** Characteristics of the three Model Home 2020 houses represented through photos of details, main floor plans with indication of where monitor screens are situated, brief description, size and number of floors. Further, photos of monitor screens and weather stations in each house are presented.

## Test-families

To explore how the houses and their systems function in use, test families live in each house for one year. Please see Figure 2 for data. Test-families are selected based on a process of application from families and following interviewing and selection by members of the jury of VELUX representatives, communications experts and psychologists (Bruun 2013). Families are selected to resample an average family from the specific country and are characterised by being young families of a mother a father both working full time and with two kids, in all cases boys. Please see Figure 1. This selection process carries bias as VELUX is represented in the juries.

The test houses are owned, designed and built by separate national sections under VELUX /AS. With this set up a ray of practical measures have to be taken. Therefore, synchronized test-periods are not possible which cause uncertainties such seasonal variation (spring in one year most likely do not resemble spring the next year), time of year for moving in (moving in to a house and area during summer is probably very different from moving in during winter), and weather (one year might produce much more hour of sunshine than the next one).

## Interfaces

Encounters between user and automation happen through monitors, remote controls and

switches. Two monitor types are installed in the houses respectively a Visualization MWa Touch and a NV Comfort. MWa Touch (please see Figure 3) is the main screen displaying information about energy production and consumption, indoor environment and weather, including graphical representation of data going back twelve months. This functions as the main screen and is the screen to consult in search for information or to adjust or configure settings. The NV Comfort (please see Figure 4) is a smaller monitor containing mainly information on comfort aspects, as the name implies. The graphic interface is pedagogically designed with one small square to represent each zone in the house; here temperature, CO<sub>2</sub> and relative humidity levels are displayed, and whether, if artificial light in the room is on or if a window is open or the shutter down is also indicated. Remote controls belong to VELUX roof windows and can be programmed to control the roof windows in the house either individually or compiled into groups. Remote controls sit on the walls in all spaces with roof windows but can be picked up and taken along. Lighting switches are also in all spaces with the primary aim to switch on/off lights. Besides lighting control some of the switches are able to drive down external or internal screening. Please see Figure 1.



**Figure 3. MWa Touch screen.** The main monitor screen in the house where data can be assessed and occupants can acquire feedback and change settings.

**Figure 4. NV Comfort screen.** The smaller screen where occupants can change indoor environmental settings and adjust blinds and screening.

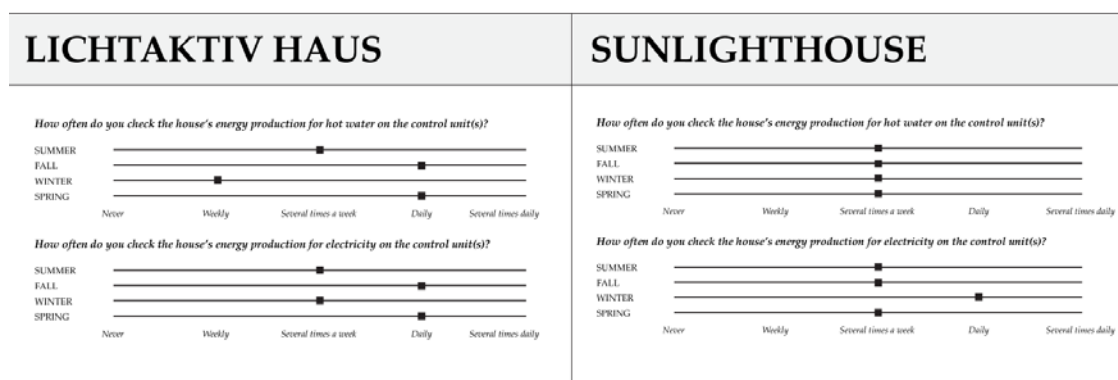
## Findings

Findings on occupants' experiences of respectively consulting and operating the system and on automation are illustrated. Also selected findings on energy, indoor climate and health relating to the system are presented. Not all data from the extensive collection could be presented; why phrases commenced to best communicate occupants' experiences are selected. Communication of results are to a wide extent based on occupants' own words via citations, as to convey their experiences as purely as possible.

Methodological differences, strengths and weaknesses to the methods will be reflected in the later discussion.

## Consulting the system

Questionnaire studies on consulting the systems provide insights into occupants' experiences of interaction and on frequency of interaction as illustrated in Figure 5. SLH and MAL occupants are very consistent in the way they perceived their own behaviour, whereas LAH occupants seemingly vary their consulting patterns more. No seasonal patterns are identified.



**Figure 5. Consulting the system.** Results of questionnaire data analysis displaying how often occupants experience consulting the systems in the respective houses to check for energy production and consumption.

Blogs exemplified occupants' first encounters:

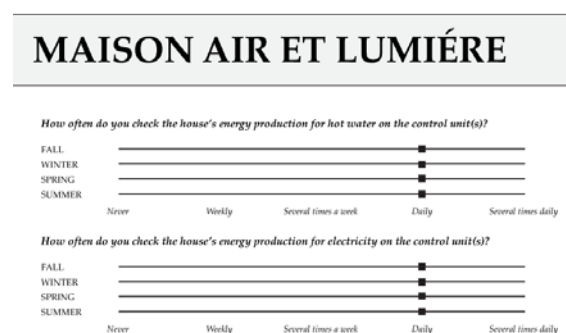
*"The actual settling lasted a few days. Especially the use of the building technology was a little unusual. It is roughly comparable to the early days where you have a new phone in use."* (Occupant in SLH, 21st April 2012, from blog)

At first occupants are overwhelmed by technologies, a finding common to the houses, but after living in the houses for a while they got used to the systems. Findings show they after a while integrate monitors, screens and remotes naturally in their every day practices.

The intelligent system is supposedly support occupants awareness, but also knowledge about own consumption and they regularly (daily) consult the monitor to know about their 'energy where-about':

*"We've got it simple. A look at our large monitor screen and we already know the consumptions of the last days, weeks or months for electricity, heating, water, or hot water."* (Occupant in LAH, 19th October 2012, from blog)

Occupants express to experience information from monitors as helpful in their everyday. As the families grow acquainted with monitors they learn to recognise how different factors affect energy production:



(Figure 5 continued)

*"On the main control panel at any time, we can know the live energy of each window or photovoltaic cell of the house. Today the sun is shining we win 202 watts on a windows main roof area. With 54 watts of waste, we produce 148 Watts. I can compare it to a bright day without sunshine, cloudy or another example."* (Occupant in MAL, 22th February 2013, from blog)

Knowing production and consumption also, seemingly, affect occupants' behaviour. This is expressed by for instance occupants 'cheering' the sun to come out and balance the energy. Occupants described how they follow consequences and thereby are able to change inappropriate energy behaviour.

*"Busy lately, I left the washing clothes for several days, so last weekend was dedicated to laundry. Out of curiosity, I looked at our consumption on the screen: ouch, it hurts five laundries in one day, it consumes almost three times as much water as a "classic" day!"* (Occupant in MAL, 30th October 2012, from blog)

The educational aspects of the screen are expressed throughout the blogs and some phrases even indicate that mood is quite affected about this awareness:

*"March is a real sun month! The recording on video monitor is to see that no other month has brought so much solar energy (not to be confused with PV!). On the other hand at the moment we have to get our water through the "normal" lines, which means an increase in consumption, especially when watering the lawn currently it is extremely high"* (Occupant in LAH, 28th March 2012, blog)

Getting used to consulting monitors entails suggestions for optimisation from occupants themselves:

*"With us, not a day goes by without a glance at the video monitor to see what our energy roof harvested, and how much daily consumption of electricity, water and heating was. We are in the positive range of the energy revenue... and this pleasant feeling I should be happy to include any in its price quote!" (Occupant in LAH, 16<sup>th</sup> October 2012, from blog)*

Easily accessible visualization motivates occupants to consult systems for information additionally creating a feeling of being happy.

*"I love to know in real time what we consume and produce!" (Occupant in MAL, 22<sup>th</sup> February 2013, from blog)*

## Operating the systems

Questionnaire research show that occupants perceive to most often use the 'screen' to operate indoor climate, prefer operating by screen, and find the screen 'very easy' or 'easy to some extent' to use. The occupants find it easier to use the control units the longer they live in the house. There is a tendency that the longer the occupants live in the house they increase the frequency in interactions with screens. Ability to control, adjust and over steer create a feeling of increased satisfaction. See Figure 6 for detailed outcome.

To change settings or to adjust, for instance, shutters occupants can customize systems in accordance with their specific needs.

*"We have the opportunity to act on many parameters: the temperature of each room, opening windows, blinds, natural or mechanical ventilation, etc. Each piece is customizable. We started to change some to appreciate the differences." (Occupant in MAL, 6<sup>th</sup> October 2012, from blog)*

Knowledge of possibilities of customisation increases occupants' awareness of comfort needs.

Besides the large monitor screens lighting switches and remotes for operating roof windows are also operable systems to adjust the environments to occupants' needs. Occupants experienced not only the technical systems in the houses as new but also lighting switches functions differently compared to what they are used to. This causes annoyance:

*"On my first visit in Sunlighthouse I stood in the nursery and wanted to test the lighting. Since lamps were almost seen nowhere, I could not imagine how the room should come to light. But I failed much before finding out - at the light switch. Not just a toggle switch, as we know, but on the same area six buttons. So what, then, makes light? The first thing I have learned about what works better is the left and right. So not to turn on one side and a side to make up, but both on both sides. And the top is the most important. I would have thought the bottom, but that does not control light, but controls the ventilation. The next thing I learned: it can happen. So press. But if you, as usual, hit the centre of the switch, nothing will happen - because there is no button." (Occupant in SLH, 7<sup>th</sup> May 2012, from blog)*

Occupants are faced with a new way of living and especially a different level of integration and collaboration with the house. The intelligent system is important to support users comfort needs and displays provided information from the state of the house to the occupants. This gradually becomes an integrated habit.

## Automation

Questionnaire research show that occupants in all houses experience the way the system operated the houses 'to some degree' support their needs throughout seasons. LAH occupants are a bit more satisfied during summer and winter where they experienced the system 'yes, very' support their needs. Questionnaires also show that occupants are 'very satisfied' or 'satisfied' with the way the house systems are operated by automation. Almost a third of replies show occupants are 'very satisfied' while a two thirds are 'satisfied'. Only two of 84 answers show direct 'dissatisfaction' with automation. See Figure 7.

Blog findings on automation show that the occupants in the different houses peruse different approaches to living with automation. They chose different strategies.

Blogs indicate that these choices seem to be based on knowledge acquired through information from teams and technicians behind the houses paired with interests and beliefs on what was the better approach.

SLH occupants express great confidence in automation and let settings control automation without intervening:

*"The house actually works automatically when no one intervenes. (...) A good strategy has proven to leave the the building services to the system. If this is set well it contributes to not worry that the house can withstand a heat wave well. Especially if you go to work in the morning you don't need to worry about letting the heat protection elements down. They go down by themselves when the sun comes." (Occupant in SLH, 3<sup>rd</sup> July 2012, from blog)*

The approach of letting the system control automation also gives the occupants a feeling of not needing to worry about it. This implying they trust the system handles issues and optimizes the house to their needs.

LAH occupants have a slightly different approach as they intervene by for instance opening windows if they feel the need.

Simultaneously they express to appreciate automation, especially after experiencing a period where it was set out of function:

*"In recent days, we quickly realized how pleasant it is to have an automatic control of ventilation with natural air flow and the importance of independently operating shading in the different rooms." (Occupant in LAH, 12<sup>th</sup> June 2012, blog)*

MAL occupants in general describe automation fulfilling their needs. Simultaneously they are caught off guard by transition from summer to winter settings and thereby new aspects of automation:

*"Mechanical ventilation fan takes over from windows to change the indoor air. We must get used to the air from the vents. We shifted the nozzles up to avoid feeling the air directly to us." (Occupant in MAL, 1<sup>st</sup> November 2012, from blog)*

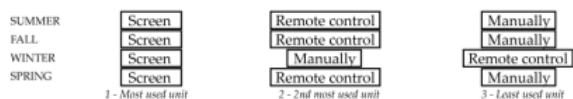
The three different in-use patterns are illustrated; none truer than the next one.

Occupants in general express great confidence in automation taking care of airing out the house and providing fresh air; but they also experience down sides to automated natural ventilation:

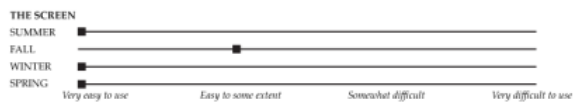


# LICHTAKTIV HAUS

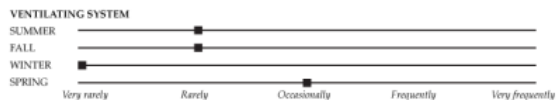
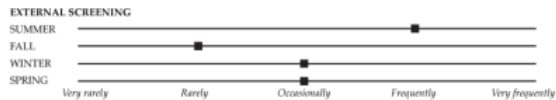
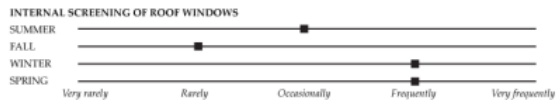
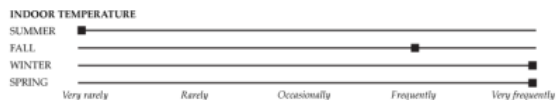
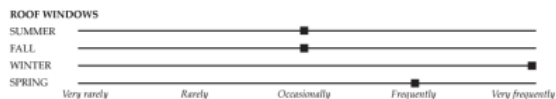
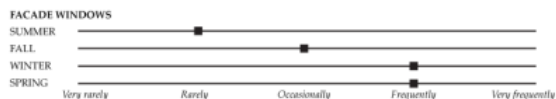
Which control unit do you use most often to operate the indoor climate in the house?



How do you find the usage of the control units?

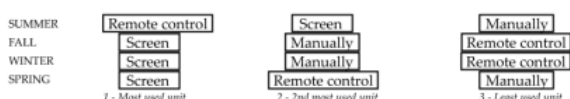


During the last couple of weeks, how often have you used either the screen and/or the remote control to operate the house systems?

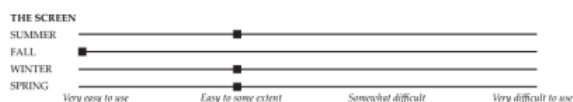


# SUNLIGHTHOUSE

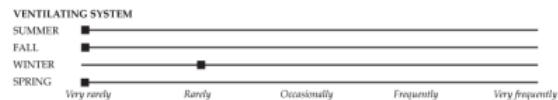
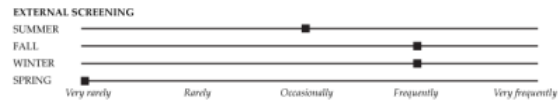
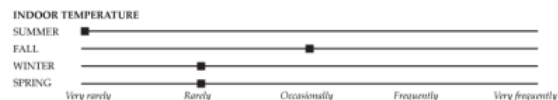
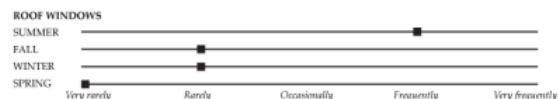
Which control unit do you use most often to operate the indoor climate in the house?

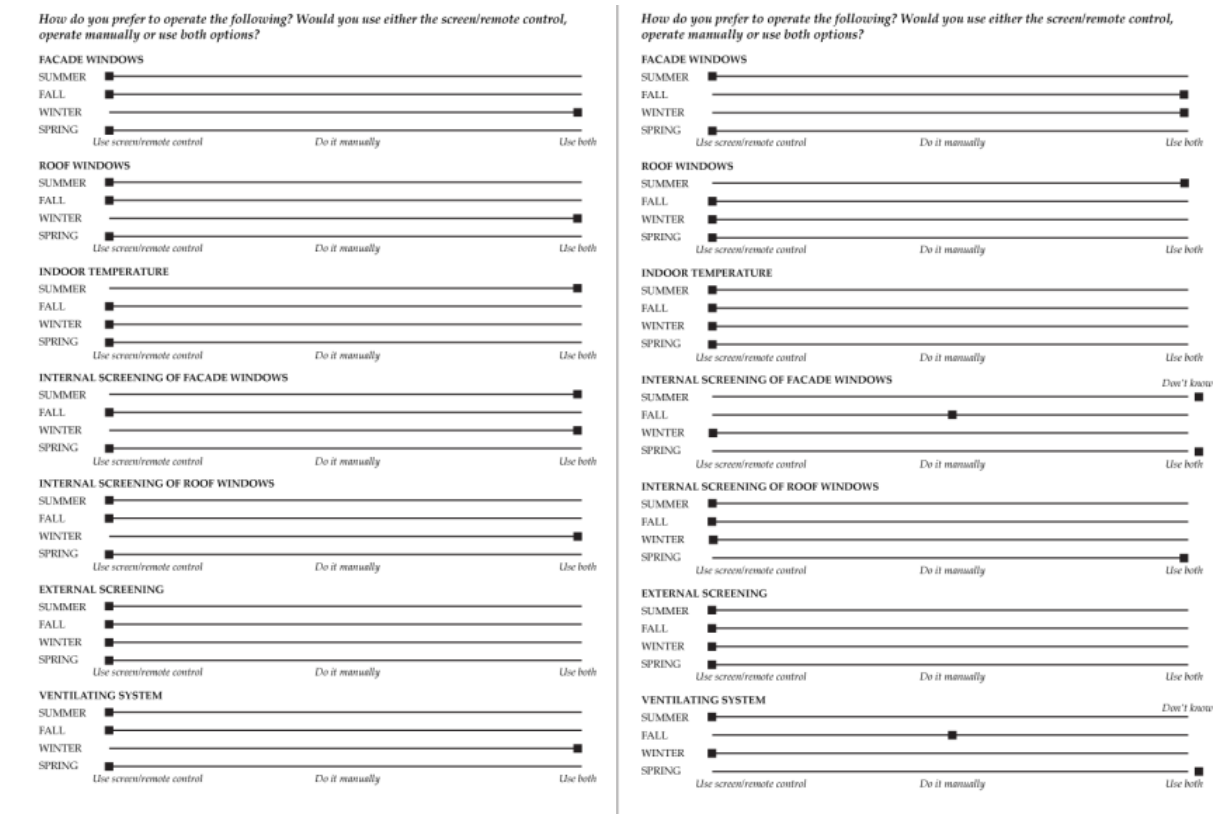


How do you find the usage of the control units?



During the last couple of weeks, how often have you used either the screen and/or the remote control to operate the house systems?





**Figure 6. Operating the system.** Results of questionnaire data analysis displaying occupant experiences of operating the house automation.

“Late summer they are particularly numerous. Greedy and annoying they are always - the wasps. If you live in the countryside and have numerous windows that are automatically open for ventilation in the evening they go towards the bright lights from inside (...) Because, normally you open and close a window by hand to ventilate and may for this time turn off the light or only open windows night when it is already in the dark.” (Occupant in SHL, 9th September 2012, from blog)

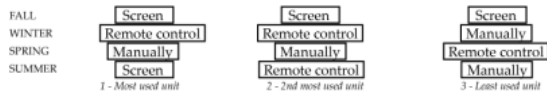
Negative experience is often related to automation suddenly doing something

unexpected, underlining that expectations and knowledge is important to successful experience of automation:

“These last two weeks have been very windy. For safety the system raised the blinds. But this time, no “yoyo”. (...) When the wind blows hard the night, the blinds can be traced back all at the same really startling us.” (Occupants, MAL, 9th November 2012, from blog)

# MAISON AIR ET LUMIÈRE

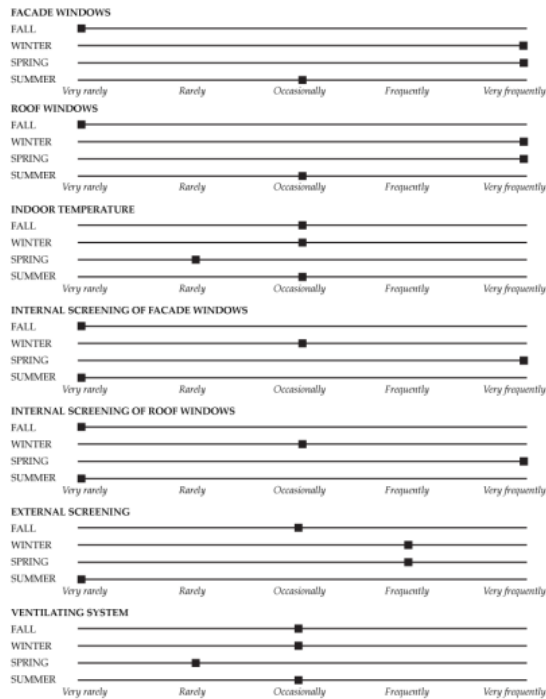
Which control unit do you use most often to operate the indoor climate in the house?



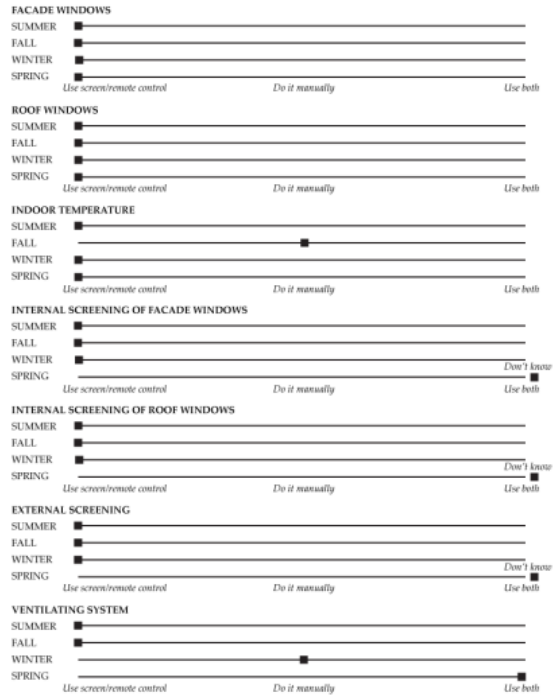
How do you find the usage of the control units?



During the last couple of weeks, how often have you used either the screen and/or the remote control to operate the house systems?

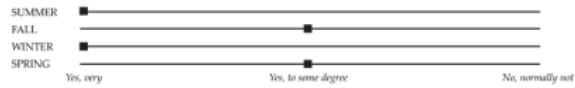


How do you prefer to operate the following? Would you use either the screen/remote control, operate manually or use both options?

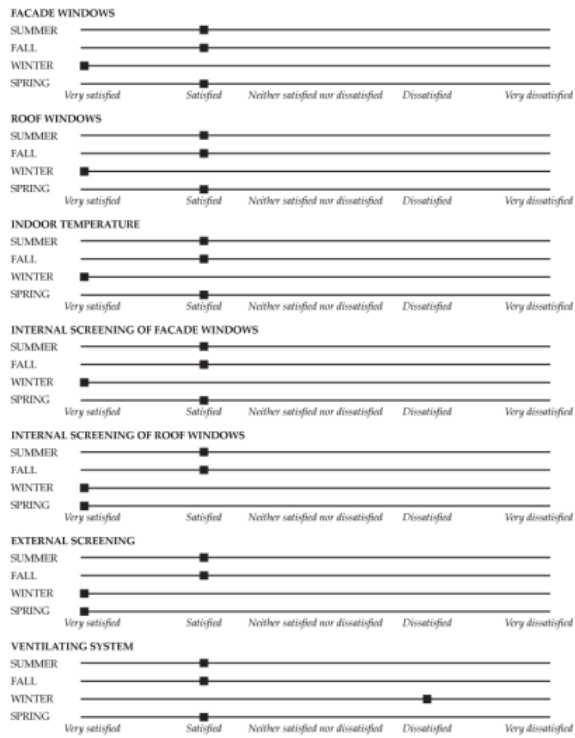


## LICHTAKTIV HAUS

Does the way the control units operate the house systems support your needs?



To which degree are you satisfied or dissatisfied with the way the house systems are operated by the control units?



## SUNLIGHTHOUSE

Does the way the control units operate the house systems support your needs?



To which degree are you satisfied or dissatisfied with the way the house systems are operated by the control units?

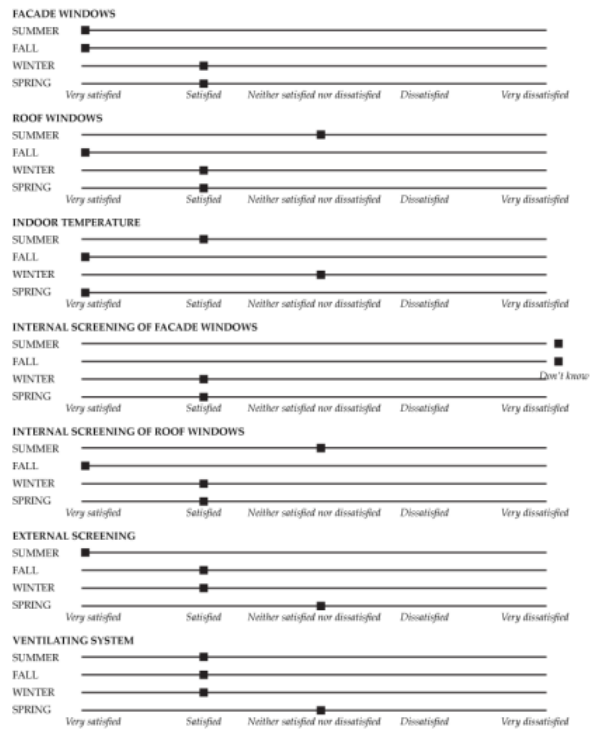
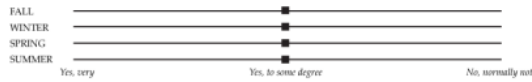


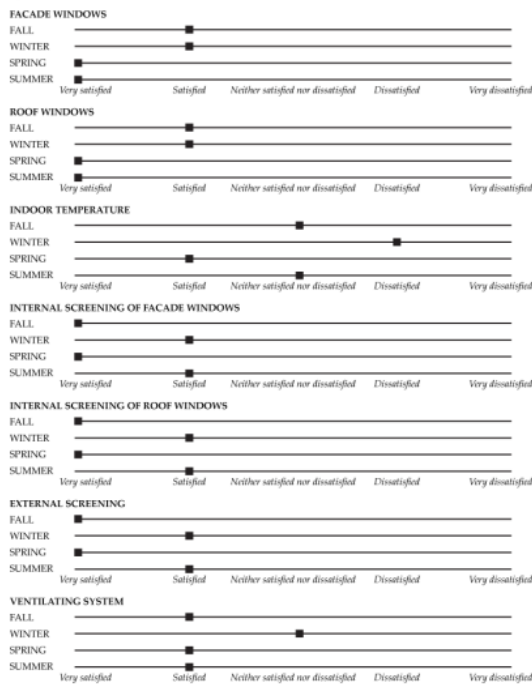
Figure 7. Automation. Results of questionnaire data analysis displaying occupant experiences of automation of the systems in the respective homes.

## MAISON AIR ET LUMIÈRE

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### Energy, Indoor climate and Health

Occupants experience turning on lights half an hour later than their neighbours or never really using light through the day:

*"No artificial light in the day! It's great that the evening light is so long, thus we come out from breakfast until long after dinner without artificial light, a great feeling. That was unthinkable in the old apartment."* (LAH, 3<sup>rd</sup> April 2013)

The occupants in all three houses further confirm this by stating consequently in the questionnaires that they use the electric lighting 'less often' compared to in their former homes. This reduction was also found

to have additional explanations, elaborated by SLH occupants:

*"Still, when I look around in the house now, we actually sit much in the "dark". This of course saves power. It has three main reasons: First, the light goes down so silently that you often do not even think to turn on the light. During the day, I almost never need light. Second, night time is either a computer or projector. Or we look at our monitors for something. Each of these devices produces light. (...) And thirdly, it is difficult to illuminate only a limited part of the house, since all the light also causes transmission. Alfred, from his bed: "Mama, Turn off the light, I cannot sleep!" Therefore, lighting on the upper floor including stairs stays off. In the morning there is enough light again."* (SLH, 7<sup>th</sup> May 2012)

Occupants experience that daylight design is integrated in lighting of bathrooms as means of reducing electricity consumption and this added quality to the light setting:

*"Especially bathrooms and toilets are usually the dark rooms in the house. A small window for ventilation is often the only inlet of daylight. In contrast, here in the parents' bathroom two large skylights (...) The daylight falls very generous in the shower, so that even in the washrooms rarely artificial light burns."* (SLH, 19<sup>th</sup> October 2012)

MAL occupants' experience great qualities of the supply of natural daylight to rooms without windows; reduction of electricity is not only about saving in the electricity bill but it is also about adding quality with light (see Figure 8):

*"We have natural light in rooms without window. (...) I had never seen this before, and this is clearly an option that we retain for our next home. As you can see from the picture, a well of natural light*

*illuminates the interior of the bathroom. This is also the case in the toilet. The light is soft and does not*

*attack the eyes. It's very nice every day. (MAL, 17th February 2013)*



**Figure 8. Natural light in windowless rooms.** A well of natural light illuminates the interior of the bathroom . Photo from occupants blog (MAL, 17th February 2013).

The quality of the electric light settings were evaluated differently by the occupants in the different houses. LAH occupants evaluated the level as 'appropriate' throughout the year and were 'very satisfied' with it. SLH occupants evaluated the level as 'appropriate' eight of twelve times and 'too much' three of twelve times and are 'very satisfied' or 'satisfied' in general with two exceptions. In MAL there was 'too much' light eight of twelve times and four of twelve was 'appropriate' and the occupants flickered between being 'satisfied' or 'dissatisfied'.

They illustrate how knowledge and information from the system makes them able

to make informed decisions on controlling systems to reduce electricity consumption:

*"(...) we learned that natural light is reflected on the windows is 25% of the energy produced by the house. This is huge! This is particularly the case for roof windows, which recovers energy from the sky. This prompts us to open reflex blinds earlier and especially do it consistently!" (MAL, 3<sup>rd</sup> December 2012)*

Reduction of electricity consumption was connected to positive mood by occupants:

*"Even on cloudy days it creates a positive mood when you hardly need artificial light. Because we look around and feel more comfortable and only*

after our Sunlighthouse experience we perceive in what dark rooms we actually spend most of our lives.” (SLH, 25th October 2012)

Occupants accentuate importance of intelligent technology to reduction in energy consumption:

“The photovoltaic system on the roof, energy-saving electrical appliances in the kitchen, energy-efficient lighting control in the living room or modern ventilation in the bedroom - your home can save lots of energy with intelligent technology”. (Occupants in MAL, 18th September 2012, blog)

Results also identify challenges to living with ‘intelligent’ systems.

“Uuuuhh, at -8 degrees you have to be quite brave when the window suddenly automatically opens...” (Occupants in LAH, 2nd February 2012, blog)

Blog and questionnaire data reveal occupants experience relations between air quality from natural ventilation and health (see Figure 9). Questionnaire results indicate that occupants in all houses experience better health:

“Right now, wherever we go, cousins or friends of Rayan and Ishmael all have stuffy or runny noses. And for us, still nothing, except for two small colds for two days we’ve had since we moved in this house! This is crazy. We were already convinced that the fresh air and heating of the house does not only heat the interior but keep it healthy too. We can now confirm that it really works!” (MAL, 20th October 2012)

Occupants experience reduced signs of asthma and allergies and reduced medicine:

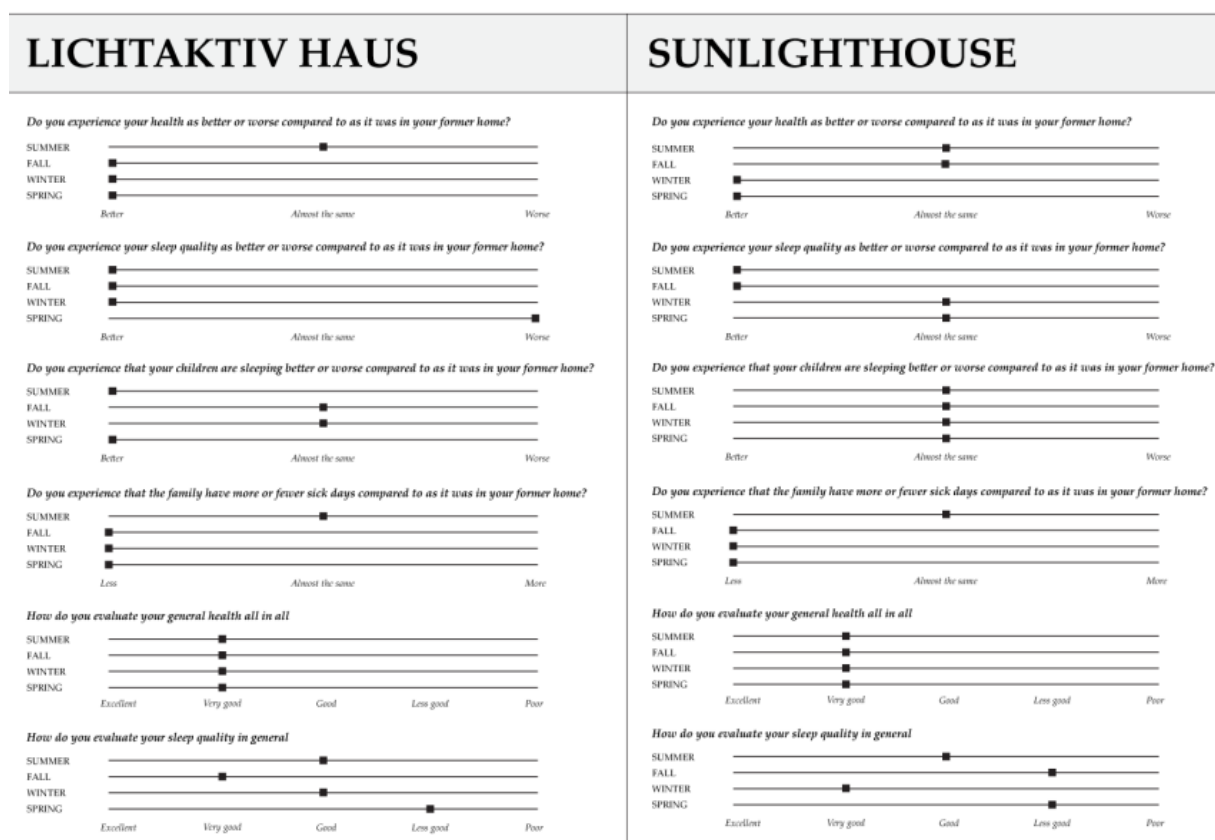


Figure 9. Health. Results from questionnaire analysis on the respective houses on experience of health in the houses.

*"What we immediately experienced is that it's like having a "breathable house" as soon as you enter. My son and I are very sensitive to pollution and poor indoor air quality. We could really feel the difference compared to our previous home. (...) Rayan, who is asthmatic, often needed to inhale Ventolin after intense efforts on bike. Here, he uses his bike as soon as the weather permits: he descends and ascends the slopes and around the forest without needing medication now."* (Occupant in MAL, 12<sup>th</sup> September 2012, blog)

When summer turned to winter the automation went from natural to mechanical ventilation; transition occupants' in especially MAL experienced as troublesome:

*"At this point, I notice that the night the children cough a little and my throat irritates me a little. I think the air is a little drier with the arrival of heating season."* (Occupant in MAL, 15<sup>th</sup> November 2012, from blog)

One blog post summons up the research findings in occupants own writing:

*"It's very interesting how quickly we have grown accustomed to the automatics and involved it in our daily lives."* (Occupant in LAH, 12<sup>th</sup> June 2012, blog)

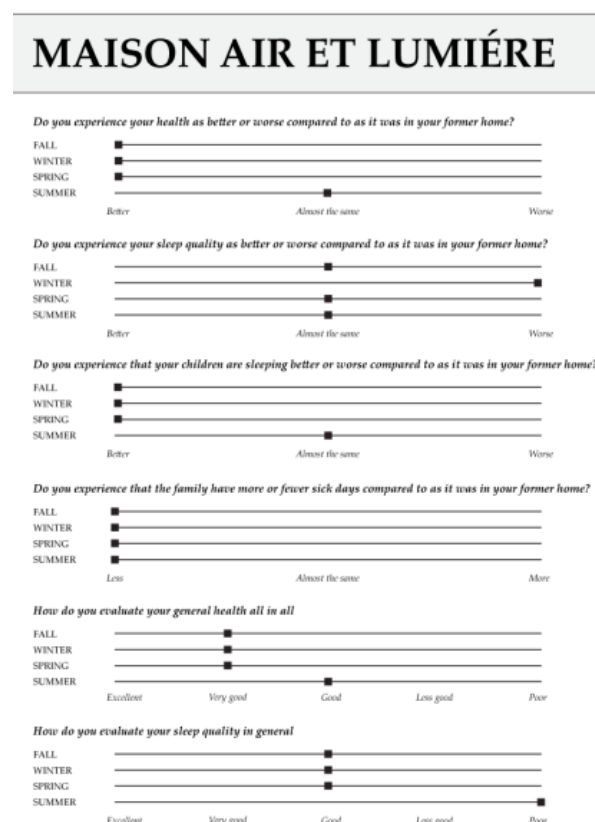
## Discussion

The following will reflect methodological approach, implications and practical significance of research findings and discuss perspectives and challenges to intelligent systems moving into homes – how do people experience sustainable functionalism?

### Methodological approach

When dealing with users as research objects the methodological approach is central in pointing out the direction of the research. Results show that the methods provide different information on the same subjects and they use different format of representation. Questionnaire research simply can be reduced to a numerical representation of results while translation of narrative statement data provided by the blog is more value loaded and thereby difficult to reduce to a number. But can their different nature then provide for comparison between the two types of outcome?

The enquiry show, that there are no blog data that exactly answer in the same way the questionnaire survey does. However, there are many of the subjects treated by the



(Figure 9. continued...)



questionnaires that are also central in the blog post as by evidence of the blog posts on e.g. automation above. Thereby, the two methods circle the same themes of interest and illuminate these in different ways.

This is to point out that application of two methods is better at capturing differences in the research than one method is. And more methods would probably create an even denser web of exploration catching more nuances. The explorations could well be followed up by in depth qualitative interviews which would create a explorative situation for digging deeper into various aspects. This would, however, be a considerably more expensive approach. Different kinds of methods from other sciences could well provide more fulfilling answers. A suggestion could be that directed blog posts could possible provide information more on the desired subjects. This could be in form of occupants relating their posts to some main topics or questions or labelling their posts with predefined labels.

In general blog method is useful for unfolding questionnaire answers. For instance as with automation, blog research exposes occupants approach to automation and illustrate their view on it. Here, it becomes evident that the three families have different approaches to managing the system. This knowledge it not readable from the questionnaire survey alone. Thereby, blog posts add a dimension to understanding that the questionnaire answers provided to the same questionnaire by the different families are in fact different. Thereby, the method provides no assurance that the different occupants do in fact understand the questions in the same way – an inherent uncertainty characteristic to questionnaire

research founded in e.g. worldview, culture and origin.

### Practice and research testing policy

The European Union aims at reducing energy consumption though supporting improvement of energy efficiency, security of supply and meeting the commitments made in the Kyoto Protocol (United Nations 1998). Behind the full scale realisation of the Active House vision materialised in these Model Home 2020 homes lie intent to put technologies available now to the test – can they fulfil 2020 goals defined by policy makers' reports and demands?

The Kyoto Protocol indicates it is about balancing the variables; this is exactly what building automation attempts; to adjust based on the actual local conditions rather than on a global idea of establishing e.g. 22°C everywhere in the house around the year. Thereby automation can help the developed technological solutions to function together in a more intelligent way. Thereby cause a likely reduction in demands of resources and create better condition for the occupants. Increased focus on making technologies and products collaborate based on the user a focal point could be an approach to making even better solutions. This may be a radical suggestion, as companies and developers behind the different technologies and products have their knowledge and earnings foundation in focus. Common political strategies could claim importance of developing solution in collaboration, possible creating profitable business for all parties.

As aspect the occupants' experiences approach to exploring home automation revealed was an importance of dynamics as adaptability over

time. This is a great challenge. Legislation and standards do not directly engage in specifying on dynamics aspects considering variation over hour and day. Occupants' experiences are valuable knowledge about what is actually going on. This type of knowledge is difficult to generate from short term studies or simulation. Very specific situations such as a storm, a very cold winter or a very warm summer are happening causing extremes, and these extremes are the ones difficult to handle by rules and legislative demands. Maybe attention towards extremes is an approach to better handling comfort demands and experiences of automation success in future sustainable homes?

### Challenges and perspectives

In encounters between occupants and technology feedback is to a wide extent experienced helpful. But challenges and annoying aspects are also experienced, and these should form the focus in future development. Blog posts indicate that aspects such as insects, wind and shift from summer to winter are challenging to maintaining comfortable environment to the occupants. Are these Model Home 2020 houses extra fragile to natural elements because they are designed with awareness of natural resources? And is this nearness to nature not a quality to the occupants?

## Conclusion

With introduction of intelligent technologies in homes there is talk of a new form of sustainable functionalism that integrates technical ability with user experience by providing feedback on actions.

Encountering sustainable functionalism in Model Home 2020 homes to a wide extent depends on how automation is experienced by the occupants to comply with their needs; that occupants are not afraid of technologies moving in but rather have great confidence in them; and that application of additional systems is desired by occupants to cope more precisely with variability.

Increased transparency and information about what is actually consumed can facilitate this creating awareness of what impact different actions in fact have. This information is an important tool for the occupants.

Building industry is encouraged to focus on designing systems and houses in cross-disciplinary collaboration that integrate intelligent technologies from the first design steps and develop products based on insight in user needs and experiences. The explored solutions of sustainable functionalism indicate increased information and knowledge encourage occupants to a more conscious behaviour. This insight could well for the basis for further development of sustainable everyday life.

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***Enquiring Perceived Quality in Sustainable Architecture: A More Tangible Approach***

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# Enquiring Perceived Quality in Sustainable Architecture: A More Tangible Approach

*Based on a critical view on recent directions in development of sustainability this article aims at making perceived quality in sustainable architecture more tangible. The paper is founded in phenomenological approach to perceived quality through empirical enquiry of three energy plus Model Home 2020 houses in-use. Based on theoretical enquiry a scheme is formulated as a registration device, used to collect, treat and disseminate elements of perceived quality. Conclusions are that elements of perceived quality are present in these Model Home 2020 buildings and can be registered, analysed and disseminated through use of the developed scheme. These values cannot be captured through means of technical measurements. Thereby, the enquired buildings are sustainable in more than a technical sense and can due to their perceived architectural quality be for the benefit of occupants and thus contributing to their well-being.*

## **Keywords**

Everyday building, Perceived quality, Phenomenology of perception, Sustainable, Tangible



## Introduction

Development of sustainable architecture was for decades driven by technological progress<sup>1</sup>. It existed as a subculture in architecture strongly connected to engineering aspects and discipline. Maybe therefore it was kept at arm's length by most architects?<sup>2 3 4 5</sup> Due to this course of development, assessment of the value of sustainable buildings is based on rather technical approaches, mainly numbers, intervals, percentages and ratings.<sup>6 7 8</sup> Engineering science uses these indicators to quantify the quality of aspects explored. For instance, temperature is used as indicator for the quality of thermal comfort.<sup>9</sup> This is a well known and commonly accepted measure, but what does it really tell about the qualities of a building? Spot measurement can tell of a structures thermal ability under specific circumstance. Measurements for longer periods can tell of the abilities over a time span. But is such a simple measure adequate to illustrate thermal quality in general?

## Background

Buildings are composed by walls, windows, doors, floors and ceilings, all physical elements assembled in the complexity of architecture. However, architecture is also about aesthetics, sensuous and perceptual aspects. These aspects have been overridden due to argued technical knowledge and methodology, even though historically these aspects received most attention when designing buildings.<sup>10 11 12</sup>

Architects Steen Eiler-Rasmussen<sup>13</sup>, Jørn Utzon<sup>14</sup> and Alvar Aalto<sup>15</sup> were central in (re)establishing attention to sensuous aspects of architecture. Through their inherent understandings of how structures and spaces can create value for the human being they explicate a sensuous and perceptual approach to architecture and demonstrate an inherent

and bodily understanding for human beings. Utzon writes:

*'It demands a good healthy common-sense understanding of life. An understanding of walking, standing, sitting and lying comfortably, of enjoying the sun, the shade, the water on our bodies, the earth and all the less easily defined sense impressions. A desire for well-being must be fundamental to all architecture if we are to achieve harmony between the spaces we create and the activities to be undertaken in them. This is quite simple and reasonable.'*<sup>16</sup>

Contemporary architects as Peter Zumthor<sup>17</sup>, Steven Holl<sup>18 19</sup> and Kengo Kuma<sup>20</sup> among others work with the concepts of atmosphere, imagination, perceived quality, poetics of space, and sensuous space in their architecture. They are renowned and awarded for their buildings; their focus is considered important.

## Approaches to comprehend

In order to understand perceived quality, approaches to conceptualise this are attempted by researchers in the cross-field between architecture and sustainability<sup>21</sup>. Luring and Marsh<sup>22</sup> reflect *Architectural Quality of Low Energy Houses* against Vitruvius' concept of architecture in function, strength and beauty. A similar approach is asserted in Brunsgaards' <sup>23</sup> study of *Architectural Qualities in Passive Houses* as she as well uses Vitruvius' categories aspects of quality. In her dissertation Wraber<sup>24</sup> explores *Architectural quality in Danish prefabricated wooden dwellings* studying how aspects of structuralism, perception psychology and phenomenology can frame facets of quality in prefabricated architecture. In continuation of Wrabers studies Bejder's<sup>25</sup> dissertation studies *aesthetic qualities of cross laminated timber* through establishing concepts of respectively technology, material and materiality. Christoffersen<sup>26</sup> explores Architectural Quality by establishing a range of categories that all

provides aspects of quality in architecture. As one parameter she speaks of Sustainability:

*'So you could say in a way that architectural quality is a robust size, in the sense that if one builds with architectural quality then you have actually made a built-in sustainability, so actually they build with sustainability because it is durable. (...) Surroundings built with architectural quality can stand to be worn without losing their value.'* <sup>27</sup>

The research projects mentioned above all bring a ray of aspects to approach understanding perceived quality and thereby attempt adding tangibility to the concept. Nonetheless, there is a lack of directly exploring the terms in an empirical context, where aspects are included in the complexity of the built environment. Also, the conceptualised parameters are not explicitly reflected into a tangible format for practical use.

This paper contrarily aims at composing a scheme for registration of perceived quality in sustainable architecture by studying architects approaches paired with sensuous bodily enquiry to create a frame for identification central aspects. The aim of the scheme is to create a frame for respectively registration, analysis and dissemination of aspects of perceived quality. Thereby, the scheme should function as a memo for exploring all aspects; respectively during field study, analysis and will together with other data, like quantitative and other qualitative data give a better picture of the overall architectural quality of a sustainable building.

How can aspects of perceived quality in sustainable architecture be registered, analysed, assessed and conveyed without losing their architectural value?

## Methodology

The methodological approach employed in this research is based on deductive reasoning

compiled in a multi perspective and mixed methods approach.<sup>28 29</sup> The mixed perspectives approach is based on compilation of theoretical and empirical approaches where the theoretically developed registration scheme is reflected against empirical enquiry in a bodily sensuous encounter. The approach covers various methods for registration, amongst them photography and notes.

### Capturing perceived quality

Qualitative ways of assessing architecture is a discipline in development. Application of methods and approaches from other sciences, mainly social and humanistic sciences, is increasing.<sup>30</sup>

Often, architectural qualities are portrayed and disseminated through photography in everything from architectural magazines to tenant ads. Visual ethnography is a recognized field of science using photo and film as medium to capture knowledge. Pink explains the approach of visual ethnography:

*'The way in which individual ethnographers approach the visual in their research and representation are inevitably influenced by a range of factors (...) Fundamental to understanding the significance of the visual ethnographic work is a reflexive appreciation of how such elements combine to produce visual meanings and ethnographic knowledge.'* <sup>31</sup>

Thereby she stresses the relation between the in-situ experience and the photograph as a means to capture and register knowledge of perception. In SBI's publication *Light in the School* <sup>32</sup> a scheme for qualitative registration of light conditions in schools is concretized by structuring a diagram format where assessment of selected parameters consist in written descriptions and observations accompanied by a list of questions to elaborate the themes. This reflects a more structured approach. Common to the methods are a focus on registration of

quality and sub-devision of explored aspects of interests.

### Bodily and sensuous approach

Juhani Pallasmaa writes in *The Eyes of the Skin*: 'Every touching experience of architecture is multi-sensory; qualities of matter, space and scale are measured by eye, ear, nose, skin, tongue, skeleton and muscle'<sup>33</sup>. Thereby he points to a core aspect, namely that understanding architecture is an act of sensuous and bodily encounters; an approach renowned architects Jørn Utzon<sup>34</sup>, Alvar Aalto<sup>35</sup>, Steen Eiler-Rasmussen<sup>36</sup> and Steven Holl<sup>37</sup> support. This leads to wondering, how these architects approach understanding perceived quality?

Firstly, the foundation of perceived quality in architecture is explored through the theoretical enquiry of atmosphere and beauty <sup>38 39</sup> and an empirically based approach through phenomenology and the senses<sup>40</sup>. Following, enquiries explore selected architects' approaches to putting terms on architectural quality and include Steven Holl<sup>41</sup>, Juhani Pallasmaa<sup>42</sup>, Steen Eiler Rasmussen<sup>43</sup>, Florine Sack<sup>44</sup> and Peter Zumthor<sup>45</sup>. The literature enquired though this paper is merely a selection of literature on the subject of perceived quality. The choice is of books rather than articles. The selection was made, as Eiler-Rasmussen, Pallasmaa, Holl, and Zumthor are commonly, amongst architects who are considered ancestors to the bodily and sensuous experience of architecture why they are obvious to include. Sack is included as she represents a different approach which is based on more examples and on a thematic strategy. Her focus on encounters between architecture, nature and experience through the 'open house' represents a sensuous female approach where softer aspects are focused on. Her take on dissecting architecture to get to know it is interesting to enquire, as she uses the encounter

to illuminate all the different aspects. Thereby, her presence in this fine company can be justified.

Enquiries result in identification of a range of parameters. These parameters are categorized and reflected on empirically perceived examples of authors own sensuous and experiential means. The studies result in compilation of a conceptual device for capturing aspects of perceived quality through an in-situ approach applying senses measurement. The parameters are formulated into a scheme format to collect, treat and disseminate.

The registration scheme is tested in exploring perceived quality in three sustainable homes. The three houses are all built on the basis of the Active House vision and are included in the Model Homes 2020; a strategy exploring aspects of how homes can be in 2020 with the technologies available today<sup>46</sup>. Characteristics of the houses are presented in Figure 9. Data is compiled during in-situ registration trips to each of the houses for a three day period.

The approach is based on experience studies inspired by architectural theory and phenomenology dealing with the hybrids between bodily and spatial experience.<sup>47</sup>

Finally, discussion will reflect on possible implications for the knowledge area and development of sustainable architecture and possible future directions of the work.

### Enquiring perceived quality

How can perceived quality be made tangible? Through enquiring writings by architects who approach architecture in a sensuously and bodily way, the question is reflected: How do architects approach understanding and conceptualising perceived quality?

## Sensory approach

In 1957 Danish Steen Eiler-Rasmussen wrote *Experiencing Architecture*<sup>48</sup> a book which has since been an essential part of architectural theory and education. Through the book Eiler-Rasmussen pedagogically lead the reader through his sensuous approach to architecture and argues that architecture should be experienced in real life and not by readings or illustrations of it. He explains:

*'Understanding architecture, therefore, is not the same as being able to determine the style of a building by certain external features. It is not enough to see architecture; you must experience it. You must observe how it was designed for a special purpose and how it was attuned to the entire concept and rhythm of a specific era. You must dwell in the rooms, feel how they close about you, observe how you are naturally lead from one to the other. You must be aware of the textural effects, discover why just those colours were used, how the choice depended in the orientation of the rooms in relation to windows and the sun.'*<sup>49</sup>

Through *Atmospheres*<sup>50</sup> and *Thinking Architecture*<sup>51</sup> Peter Zumthor articulate what motivates him in his approach to architecture. He dissects experiences meaningful to him in his quest for understanding his own architecture. He describes how spaces can have a sensual effect on him:

*'To me it's a kind of anatomy we are talking about. (...) As a bodily mass, a membrane, a fabric, a kind of covering cloth, velvet, silk, all around me. The body! Not the idea of the body – the body itself! A body that can touch me.'*<sup>52</sup>

Florentine Sack's *Open House*<sup>53</sup> represents a motivating approach to how architecture comply with increasingly complex demands in rising user needs and influence relations between man and his environment. She explores contemporary, built examples by reflecting on architectures ability to correspond

to the variety of forms, colours, materials and sizes through respectively intuitive, holistic comprehension and rational evaluation. *'Instinctive perception is always ahead of the intellectual process.'*<sup>54</sup>

Juhani Pallasmaa's *The Eyes of the Skin*<sup>55</sup> is commonly considered fundamental in architectural theory in line with Eiler-Rasmussen's *Experiencing Architecture*. Through the book Pallasmaa critiques the course in contemporary architecture to rely only on visual realms and argues experiencing the world is created by combination of all senses in the sensuous encounter. In his concluding remarks he pleas for full understanding of human condition and integrity of architecture; an embodied memory:

*'An embodied memory has an essential role as the basis of remembering a space or a place. (...) In memorable experience of architecture, space, matter and time fuse into one singular dimension, into the basic substance of being, that penetrates our consciousness. We identify ourselves with this space, this place, this moment, and these dimensions become ingredients of our very existence. Architecture is the art of reconciliation between ourselves and the world, and this mediation takes place through the sense.'*<sup>56</sup>

## Aspects of perceived quality

The selected works exemplify how architects articulate quality through terms, descriptions and illustrations (however, illustrations not reproduced here). There appear to be coincidence in the subjects reflected by the different authors. Similarities in terms or content used reflect the works, more or less, speak of the same themes. Characteristic to the themes explored are they tend to describe abilities rather than the theme itself. The following exemplifies change, expressed and explored through the perspectives of three of the four architects introduced above:

## Perceived quality in architecture in the eyes of architects | literary identification of parameters

Parameters listed separately			
Steen Eiler Rasmussen Experiencing Architecture (1969)	Peter Zumthor Atmospheres (2003) Thinking Architecture (2005)	Juhani Pallasmaa The Eyes of the Skin (2005)	Florentine Sack Open House (2006)
First experiences Seeing Experiencing Coloured surfaces Proportions and scale Rhythm Texture Daylight Colour Hearing	Authenticity Anatomy of architecture Material Sound Temperature Things/objects Movement/temporal art Relation between indoor and outdoor Proximity, distance, scale, size, dimension Light (Daylight, Sunlight) Environment Coherence Beauty Seeing Experiencing Shape/form	The body in centre Multi-sensory experience The significance of shadow Acoustic intimacy Silence, time and solitude Spaces of scent The shape of touch The taste of stone Images of muscle and bone Images of action Bodily identification Mimesis of the body Spaces of memory and imagination An architecture of the senses The task of architecture	Architecture and nature Opposites Change Inside and outside Ambivalence Imperfection Plainness Growth The open house Void Authenticity
Establishing categories			
PERCEPTION	RELATION	COMPOSITION	SURFACE
Experience Authenticity Senses Well-being Comfort Thermal sensation Air quality Sound space Tactility	Surroundings Orientation Access Climate Harmony Transition Coherence Transparency Visual privacy View	Typology Shape Construction Characteristics Proportions Rhythm Spatiality Tectonics Joints Details	Ability Technology Membrane Reflectance Transparency Tactility Colour
		LIGHT & SHADOW	CHANGE
		Quality Anatomy Space Darkness Shadow Filtration Temporality	Variability Dynamics Movement Time Durability Patina Season Day
		UTILITY	
		Everyday use Automation Flexibility Furnishing Interiority	

**Figure 1. Perceived quality in the eyes of architects.** The figure displays headlines of identified parameters of perceived quality as by the selected architects. The top row lists parameters separately by author, while the bottom row establishes categories of the identified elements of perceived quality across. These categories form the further agenda for enquiry.

Eiler-Rasmussen reflects on change in relation to daylight abilities:

*'Daylight is ever changing. (...) An architect can carefully describe what quantities and qualities he wishes in his buildings. Only, daylight evades definition; as it changes from morning to evening, changes through the days of the year, and that goes for both colour and brightness.'*<sup>57</sup>

Sack reflects on relations between architecture, nature, change and light:

*'To create a harmonious effect, it is advisable to integrate temporary light conditions into the design, as well. Different times of day and the seasons have their own specific world of colour, which can be charmingly on a house that is painted in tones that are analogous to nature.'*<sup>58</sup>

Pallasmaa reflects on change in time and the impression time leaves on materials:

*'Natural materials express their age and history, as well as the story of their origins and their history of human use. All matter exists in the continuum of time; the patina of wear adds the enriching experience of time to the materials of construction.'*<sup>59</sup>

## Identification and categorisation

Enquiries of the four works are deduced into heading of themes and aspects. The identified parameters are listed in Figure 1. Identified coincidences in the works create a foundation for categorising adjacent aspects. Therefore, analyses lead to a structuring of seven themes, specifically: *Perception, Relation, Composition, Surface, Light & shadow, Change and Utility*.

### Exploring categories

Categorised parameters are explored through examples of perceived quality with the purpose of valuing, motivating and illustrating their perceived impact. All examples represent sensuous and bodily encounters by the main author and all figures are captured in relation to the experiences.<sup>60</sup>

## Perception

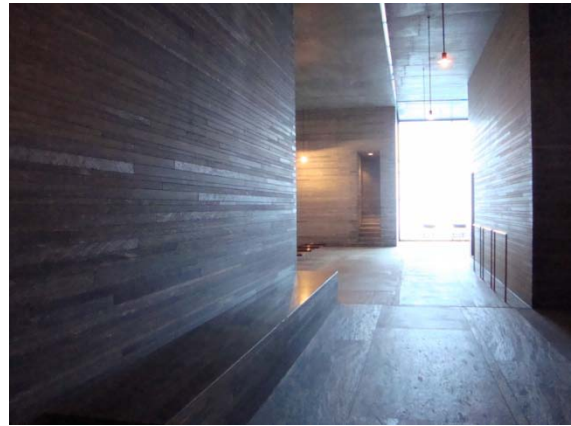


Figure 2. *Perception*. Therme Vals, Vals, Graubünden, Switzerland (1996) by Peter Zumthor. Composition, relations, surfaces, light & shadow, variability and utility come together in this building and create a sense of refined intimacy through simple means that has a strong effect on the senses.

Peter Zumthor's Therme Vals, in Switzerland (Figure 2) is an example of architecture which engages the senses and creates a direct bodily relation to space. The nakedness is part of the experience and intensifies the bodily meeting with the spaces. A direct sensuous encounter providing experiences for all senses through composition of indoor environment. The monolith structure appears as if cut out of the heavy stone, and baths are composed into the raw geometry.

## Relation



Figure 5: *Relation*. Experimental Summer House, Muuratsalo, Finland (1953) by Alvar Aalto. A small stairs is integrated in the landscape.

Alvar Aalto's Experimental Summer House in Muuratsalo (Figure 3) is situated in the Finnish nature with respect for the luxuriant surrounding. Aalto has placed his buildings with regards to the existing nature and trees are preserved with the main buildings swerving around it. But the piece that best accentuate the architects respect and admiration of nature is a small wooden stairs integrated between the protrusions rocks creating a path to the lake and bathing jetty. This is a beautiful and sustainable solution to a practical challenge solved with respect for and an understanding of relation between nature and man.

### Composition

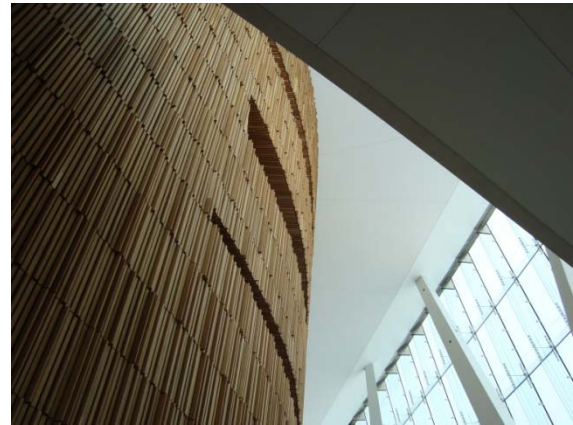


**Figure 6. Composition.** Kiasma: Museum of Contemporary Art, Helsinki, Finland (1998) by Steven Holl. View from entrance area to the grand ramp centered in the building. The different elements of straight and curved, bright and dark and flat and leaning creates the composition of the space.

The spatial expression, characteristics and proportions that portray the spatiality of a building is a composition of numerous elements. A space such as the grand ramp in

Steven Holl's Kiasma Museum in Helsinki, Finland (Figure 4) provides an insistently overwhelming spatial feeling. Long perspective, light from above, curves, tactility in materials, are some of the aspects that float together in the composition of spatiality.

### Surface



**Figure 7. Surface.** Norwegian National Opera and Ballet, Oslo, Norway (2008) by Snøhetta. Interior view in the building foyer where different surfaces, material and tactility encounters.

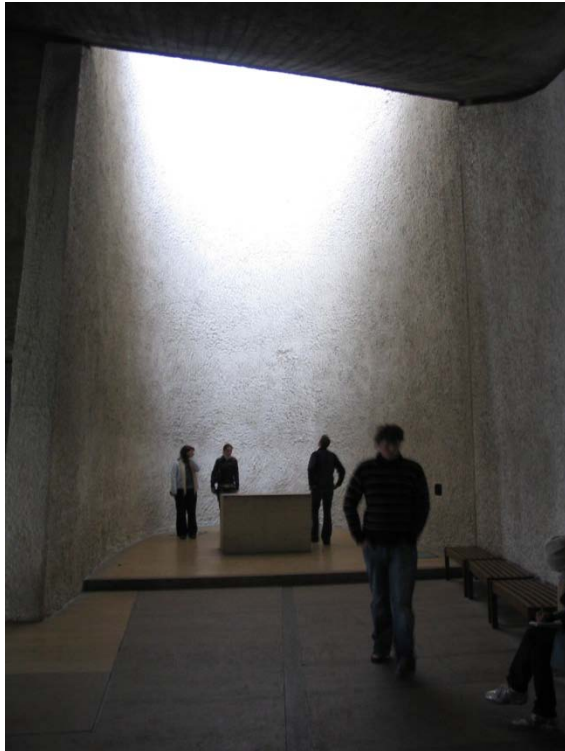
On the edge between land and water in Oslo Bay floats Snøhetta's Opera house with its white surfaces contrasting organic movements of the seascape. Visually, like a steady iceberg sculpture elongating the city onto the feral sea. Inside, the foyer encounters the body through means different surfaces. Materials, tactility, processing, reflectance, perspective and slanting columns are some of the elements in play. Especially the organically shaped auditorium adds to the experience of the foyer space (Figure 5). Contrasting its surroundings the surface is covered with wooden sticks varying in size and shape creating dynamic tactility and warmth expression.

### Light & shadow

Daylight is ever changing and thereby one thing that cannot be determined on beforehand. Light falls on surfaces, through constructions and openings and provide change and variability. Variability in light is a desired quality as it is in tension between light and



shadow aspects effects appear most accentuated. Church buildings are obvious to explore qualities of light in, as these are often clean spaces of merely structure, surface and material (Figure 6). There are numerous intense bodily encounters with light and shadow in church spaces. Le Corbusier's Ronchamp in France has manifested itself in a bodily memory with its amazing simplicity (Figure 6).



**Figure 8. Light & shadow.** Notre Dame du Haut, Ronchamp, France (1954) by Le Corbusier. In the tall church room light enters from above and spread down the ruffled surfaces creating an experience of a soft encounter between light and shadow.

### Variability

Variation over day, hour and year all bear witness of time and change. Nature, seasons, light, and habits are some aspects expressing time in architecture and materialise time in space. One example of narratives of time is the connecting hallways in Louisiana Museum of Modern Art, Humlebæk, Denmark. Architects Jørgen Bo and Wilhelm Wohler composed a structure that connects art, architecture and nature by differing their spaces, geometry, transparency etc. leading the audience through

the museum. This approach creates a building of variability adaptable to different circumstances (in nature/art) – a truly durable design (Figure 7).



**Figure 9: Variability.** Louisiana Museum of Modern Art, Humlebæk, Denmark (1958) by Wilhelm Wohlert & Jørgen Bo. The long hallways connecting different parts of the museum provides for experience of variability in creating a contrast to the enclosed exhibition spaces and by here exhibiting the variability of hour, day and year in nature and light.

### Utility

Aalto, through his buildings, creates unique syntheses of ends and means in an architecture based on sensory realism where he is able to transform necessity into poetry. With this aim he creates buildings for servicing people and not as mere technical displays. The Paimio Tuberculosis Sanatorium in Finland (1929-1933) (Figure 8) is an interesting example as the human factor is here central and evident for a successful design - an architecture designed for user needs.





**Figure 10: Utility.** *Paimio Tuberculosis Sanatorium, Paimio, Finland (1929-1933) by Alvar Aalto. Utility is highly considered in the design where details permeates solutions on all levels, like here, where the wall beneath the window is shaped to better draw in the light into the bedrooms and prevent dirt from gathering in corners.*

## Structuring the enquiry

Enquiry efforts through this paper have lead to identification of seven categories as illustrated in *Figure 1* and elaborated through the above encountering enquiries.

### Scheme for enquiry of perceived quality

This practice forms the basis for formulation of a scheme. This scheme is intended to create a more tangible frame for collecting, treating and disseminating elements of perceived quality. In a sense to make these concepts easier to verbalise and thereby include in discussions, programs, designs and weighing of sustainable buildings. This is, of course, an immense agenda thus this scheme is considered a small step in that direction. Therefore, the following description of the scheme, at how it is compiled and used is an explorative manoeuvre aiming at testing this format.

The format is inspired by respectively: *Questionnaire approach*<sup>61</sup> where aspects are rated inspired by Likert scales<sup>62</sup>, *Schematic approach*<sup>63</sup>, *Open-ended approach*<sup>64</sup>, *Visual ethnography*<sup>65</sup>, *Informal Writing Stance*<sup>66</sup> and an *In-situ approach* based on *architectural ethnography*<sup>67</sup> with the *researcher as measurement device*<sup>68</sup>.

### Four column structure

The scheme is composed as a four column structure. The first column is for the element of perceived quality in question. Thereby, this column simply forms a list of the aspects to include – a kind of memo list.

Second column *Motif* is for an illustration of the element, this be a drawing, photo, diagram, or the like. This is included to represent the quality of the elements by visual means. This is,

of course, a simplification of the sensuous means into visual medium, thus providing an idea of the aspects elaborated through *Worth*.

Third column *Worth* is for a written interpretation of the element, this might be single words or sentences. The intent here is to take the reader by the hand to guide through the collected element of perceived quality.

Column four *Extent* is for valuation of to what extent the parameter is experienced to add to the perceived quality. Thereby, this column represents a quantification of the identified elements of perceived quality.

With an intent to create and prepare for later comparability to methods and aspects of more quantitative character<sup>6,7,8,9</sup> it is enquired how these are rated; findings that commonly a five point scale is used covering to what extent the element in question comply with proposed criteria. Questionnaire research can also be based on ratings of five points<sup>28</sup>. Thereby, this proposes a five scale rating, where I is the best and V is the least good. The scale shows to what *Extent* the element is identified in the studied; with the scale: 1) *Yes, very much*; 2) *Yes, to a wide extent*; 3) *Neither/nor*; 4) *No, not really*; and 5) *No, not at all*.

Intent is that the scheme functions as both a methodological and thematic checklist during data collection; and later, the scheme functions as template or structure of analysis. Following enquiry will explore, if this scheme is in fact able to provide as tool for data collection, treatment and dissemination for aspects of perceived quality and thereby convey these elements in a more tangible way. The scheme can be found in filled in form in respectively *Figure 10(a)* and *10(b)*; be aware that these are slightly differently arranged, as they contain data from three houses.

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o  
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d  
  
G  
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K  
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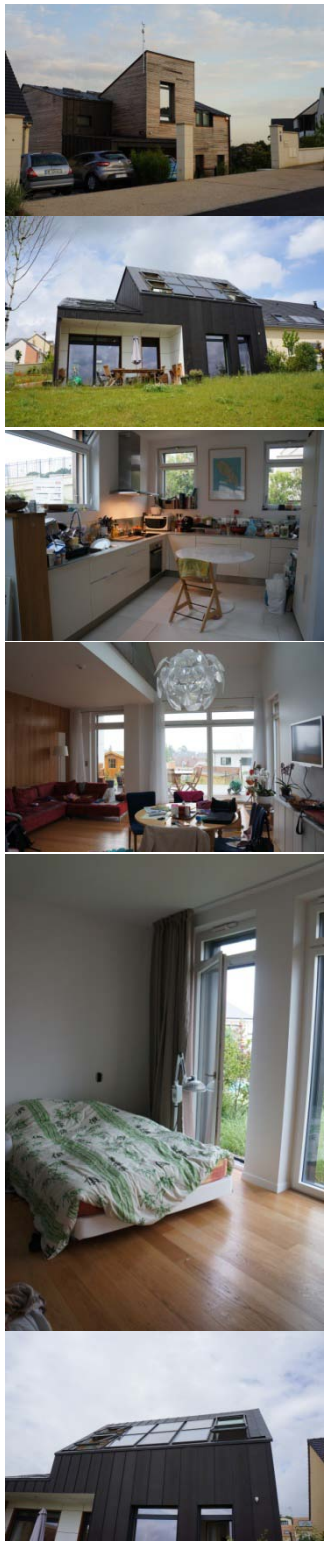
**LICHTAKTIV HAUS**  
Hamburg, Germany



**SUNLIGHTHOUSE**  
Pressbaum, Austria



**MAISON AIR ET LUMIERE**  
Paris, France



**Figure 9. Characteristics of the houses.** The figure illustrated the three houses that undergo enquiry. The houses are shown through interior en exterior photos of respectively road side, garden side, kitchen, living room, bedroom and examples of the roof integrated technologies.

## Empirical enquiries

To create a frame for exploring the compiled scheme for enquiry of perceived quality, the approach is applied to three built homes, namely three Model Home 2020 houses. Characteristics of the houses are presented in Figure 9.

Due to the character of the enquiry the quantity of data is extensive and not all data identified can be thoroughly presented here. Thus, examples are selected to illustrate how the approach is used to register and decode information through focus on aspects of perceived variability. See Figures 10(a) and (b).

### Variability

It is generally accepted that a stationary approach to assessment is the right approach – but the live that unfolds in a house, the passing of second, hour, day, season and year are all dynamic factors. These aspects of variability are reflected onto each house in question.

#### Perceived variability

The category of perceived variability can include various different aspects, such as daylight, view and space heights as illustrated in Figure 10a. Variability happens in different situations on different scales from shadow patterns moving around a space along day to the variable character of nature that in constantly changing through seasons.

#### Time

Time is explored and enquired through time lapse studies in an attempt to portray movement. Light and shadow are the only things that move while the space stand still – yet the space is perceived as changing along the day. The method of time lapse support the process of comprehending the perceptual character of these changes as it cuts them into documented stills.

### Dynamics

Dynamics is about movement and aspects of dynamic character are in many facets of the enquired houses. Especially automation is common to the houses where façade and roof windows open and close to handle the dynamics of nature and establishing comfortable indoor environmental setting.

### Durability

The subject of durability is linguistically closely related to the concept of sustainability. Is the design durable enough to sustain? The designs express their durable intentions in their different ways – LAH has a very futuristic look to it in the new addition compiled of glass.






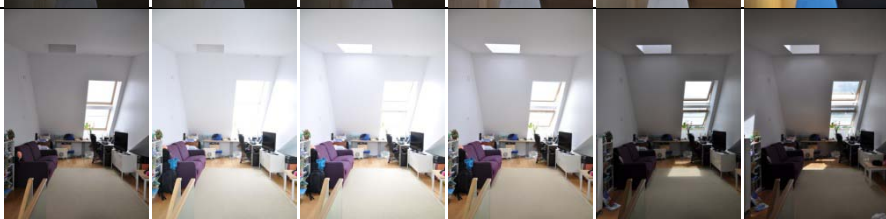
### Variability

Results on variability show that experience of variation in internal as well as external surroundings. Thereby the designs are good at making perceived variability visible. It provides feeling of calmness to be able to follow variability through the day; and the assumption is that following this through seasons and year would provide for nice experiences.

### Utility

Plan solutions are important for everyday functionality and comfort in these houses. Integration of storage elements provides for good functionality. Also interiority elements add to the usability of the spaces. Stairs in all houses obstruct possibilities of complete flexibility and living there through ones entire life.

Thereby, aspects of the category of perceived variability are unfolded.

		Motif	Worth				Extent	
Perceived variability								
L A H			<i>The daylight plays with the construction as shadows touches surfaces of covered outdoor spaces and in the staircase room. Patterns vary over hour and day and provide an ever changing narrative of hour, day, season and year.</i>					Yes, very much
S L H			<i>The situation in the landscape provides for amazing views from all floors. Near views to the private forest and long views to the mountain- and forest-scape. It is possible to closely follow the variability of hour, season and year – a changing window art.</i>					Yes, very much
M A L			<i>Aspects of perceived variability in the shifting space heights of the structure. The shape of the house expose a narrative of variability as it is compiled by differently shaped adjoining building blocks.</i>					Neither /nor
Time								
L A H								Yes, very much
S L H								Yes, very much
M A L								Neither /nor

**Figure 10(a). Scheme of results on perceived variability and time.** The figure displays results of enquiries through Motif, Worth and Extent. Motif is an illustration of the element. Worth is a description of the element. Extent is a weighing of the extent to which the element is able to provide perceived quality that adds to the experience of the house. This is rated in accordingly a scale which is structures as following: 1) Yes, very much; 2) Yes, to e wide extent; 3) Neither/nor; 4) No, not really; and 5) No, not at all. An exception is the category Time which is illustrated though photos in both motif and worth as a series of time lapse photos.



Dynamics				
L A H			<i>The tall staircase space creates an intense dynamic setting with vertical and horizontal moving paths and the plenty roof windows that opens and closes; with internal and external shading moving up and down and shadows moving around painting patterns on walls, steps and floors.</i>	Yes, very much
S L H			<i>The house has many dynamic features. In the living room space movable shutters function as both curtain and cupboard door – across from this a grand lovers-nest seat is integrated in a wall that function as storage space also. Intelligently integrated solutions.</i>	Yes, very much
M A L			<i>Facade and roof windows function as dynamic elements in the buildings shell – opening or closing changes the shape of the interior space and expression of the outer shape. This dynamic mechanism provides an impression of an organic building that interacts and reacts on its surroundings.</i>	Yes, very much
Durability				
L A H			<i>The building is put together by a classically shaped gable roof house and the new-built one sided roof added building. Shape language accentuates their different origins and illustrates honesty. The classical versus the more futuristic choice in material reflect different types of durable expression.</i>	Yes, to a wide extent
S L H			<i>The shape of the structure is very particular and moulded to seemingly exactly fit into this place – thereby it is strongly related to the place and nature – and provides an impression that it will change and transform intact with the place – expressing a very local durability.</i>	Yes, to a wide extent
M A L			<i>Durability in the interior arrangement of walls, cupboards and spaces is the frame for the life unfolded over time. Stairs and several floors are possibly not the most durable solutions – these might be challenging to (especially) children or elderly people.</i>	Neither /nor
Patina (materials over time)				
L A H			<i>Materials on the house have a rather industrial look to them and thereby a futuristic expression. Steel, light composite panes, reflecting windows, white-painted wooden columns and plaster facades. Together with solar panels and cells provide for a durable, yet rather harsh expression that does not provide an impression that it will change over time.</i>	Neither /nor
S L H			<i>The wooden house stands forth with a beautifully composed lamella cladding seemingly embracing the oddly shaped building. These are still new put will change with the temperament of the climate and overtime present the house in gray-ish tones.</i>	Yes, to a wide extent
M A L			<i>The house is clad with respectively wooden planks, a grey composite material, solar panels and cells and, of cause, windows and doors. The only one of these materials which is kept natural is the wood. At the visit the house is about one year old, and wear and tear is visible as colour differences in the west-facing wood-clad facade.</i>	Yes, to a wide extent

Figure 10(b). Scheme of results on dynamics, durability and patina. Like Figure 10(a).

## Discussion

This chapter is a discussion of the enquiry pursued, its practical significance, limitations and relevance. At last, the discussion reflects perspectives to the approach in further enquiry.

This paper proposes a scheme for registration of perceived quality in sustainable homes. By studying architects' approaches paired with sensuous bodily enquiry the work creates a frame for identification of central elements of perceived quality in sustainable homes. The aim of the scheme is to create a frame for respectively collection, treatment and dissemination and thereby, the scheme is meant to function as a sort of memo. Is the proposed format able function as a memo?

There are three main intentions behind the scheme format namely collection, treatment and distribution of data. The scheme thereby outlines what elements should be considered through these three stages, somewhat inspired by the registration scheme by Kristensen et al.<sup>69</sup>

One inherent and reoccurring problem in enquiry of architecture is the characteristic differences between architectural approaches and engineering approaches. Enquiry within engineering science is very specific and detailed with commonly defined and accepted parameters and units <sup>70</sup>. Architectural science, on the other hand, is historically a much more tacit knowledge field where enquiry is commonly based on bodily perception like shown through this article. Architects are often accused of not being explicit about their approaches and concepts of what quality in architecture actually is. Often they reside to saying something like "this is a house with good architectural quality". Thereby, this concept of what constitutes good quality in architecture remains a mystery to the not inaugurated.

This relation is problematic which contribute to creating imbalance in arguments of respectively architects and engineers. With development of sustainable architecture this divide has become even more imbalanced and therefore, sustainable architecture has been mainly developed on quantitative means. But as accentuated though this article, there also need to be quality in the built environments of the future if this environment is to create value and quality of life for occupants.

The scheme proposed through this work represents an attempt to narrow the gap between engineering and architectural arguments. Through determining elements of perceived quality in architecture the scheme creates a frame for depicting fundamental aspects. The scheme puts attention to the concepts of perception, surroundings, composition, surface, light and shadow, variability and utility.

By listing specific elements of the scheme is able to point to a range of elements in architecture that are aspects of creating quality in the built environment. Thereby focus is put to these elements and in that way, the scheme is able to make these more tangible.

### **Is it a valid approach and who can and should carry out this type of enquiry?**

Approaches based on subjective means are always questionable if considered from a scientific perspective. The results of enquiry will depend on the researcher carrying them out. As Pink puts it in explaining her take on visual ethnography: 'The way in which individual ethnographers approach the visual in their research and representation are inevitably influenced by a range of factors'<sup>71</sup>; thereby Pink points to the individual as influenced by many factors. This view requires that someone with building insights carries out this type of enquiry. Also, human insight and

bodily awareness are central characteristics to the researcher. The bodily approach is, as found, central in collection of the different sensuous impressions of perceived quality.

A weakness to the format is the inability to create consistent enquiry. A sensuous and bodily approach has this inherent insecurity, as the sensuous apparatus is something one learns to some extent through education. But is developed from stimuli, sounds, smells, tastes, visions and feelings from the very beginning of our lives shape through understanding of the world and are anchored deeply inside.

### **About going out there**

There is another aspect of the essence to touch upon. Why going there – wouldn't photos be enough? Travelling and time spend on field research is resource demanding – is it really necessary?

People live in constructed spaces surrounded by physical things; this is a multi-dimensional encounter with the world. Photos (for example) are a two-dimensional representation of the world, and despite its well developed quality and possibilities of high-pixel reproduction, it will remain two-dimensional. Scent, tactility, thermal feeling and moist of a place is basic sensuous information the body uses to understand the surrounding environment. Steven Holl puts this nicely into writing – a quote suitable for finalising this discussion:

'Architecture holds the power to inspire and transform our day-to-day existence. The everyday act of pressing a door handle and opening into a light-washed room can become profound when experienced through sensitized consciousness. To see, to feel these physicalities is to become the subject of the senses.'<sup>72</sup>

It is this 'power to inspire and transform our day-to-day existence' this work touches upon. If the homes that are developed and built for a

sustainable future manages to include aspects of perceived quality.

### **How could this enter into general enquiry of sustainable homes?**

The approach established through this enquiry attempts at creating a sort of quantification of the identified elements of perceived quality. This is done by valuating to what extent these fulfil the element in question following the Likert scale<sup>73</sup>. However, this valuation is merely based on the researcher feeling and knowledge and thereby not objective in a natural scientific sense. The elements are difficult to judge in this manner, as they are rather variable in their nature. For instance, technical enquiry values the quantity of daylight in a manner that fulfils the criteria 'the more the merrier'<sup>74</sup>. Thereby, the criterion of success is that much light makes a high rating. With aspects more perceptual aspects of light, such distinction are more difficult to make.

### **Is there a need for such an approach?**

Considering current directions in enquiry of sustainable architecture which are mainly based and focused on technical ability, the authors of this work believe there is need for putting focus to perceived aspects. With fascinating technological possibilities perceptual aspects are easily forgotten and if only technical ability is regulated from 'above'. So, despite challenges of validity and comparability, there still seems to be a need for such an approach.

### **Can it be used and contribute forward?**

Use of a schematised approach to collect, treat and disseminate aspects of perceived quality can be used forward. A next step could be, for instance, to compare the findings from this approach to technical measured findings to explore correlation and contradiction.

In training purposes for instance for architect or engineering students, such a schematic approach could be valuable. Not that the belief is, that perceived quality should be put on a formula, but a scheme like the one compiled could well function as a memo for remembering to consider elements of houses and spaces other than the technical defined and legislatively decided.

## Conclusion

Perceived qualities in the sustainable built environment should be paid more attention in development and enquiry as this creates value for human beings.

This article suggests that perceived quality should be enquired on the same level as technical ability, further, aspects of perceived quality should be implemented in legislation, as the human and the human encounter with

the built environment are central aspects in creating a sustainable future.

With composition of a registration scheme aiming at capturing, assessing and portraying elements of perceived quality a more tangible approach is suggested. This work could form a platform for further development of an actual tool to registering perceived quality in the built environment and provide for possibility to implement these aspects in legislation.

Sustainability is much more than merely technical ability. It is about creating built environments people will care for and thereby create inherent durability through the perceived qualities of everyday life. It is about creating homes and well-being in the built environment.



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***Aesthetic Quality in Sustainable Houses - Sensory Experiences of Atmospheres***

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# Aesthetic Quality in Sustainable Houses

## - Sensory Experiences of Atmospheres

Theme: *Criticism and The form of life and the form of architecture*

Keywords: Aesthetic quality, Atmosphere, Sensory experience, Sustainable, House, Field research

### Abstract

This paper seeks to explore aesthetic quality in sustainable houses by hypothesising that sustainable houses must contain aspects of aesthetic quality, because sustainability cannot be achieved solely by technical and passive means, but is a holistic matter of integration of technical, health related, social, and aesthetic aspects.

Through the paper aesthetics is considered a prerequisite of sustainability because if something is not aesthetic (beautiful) people will not develop a relation that is meaningful for them to preserve, as Thomas Sieverts argues; and Gernot Böhme points to that beauty lie in the experience of atmosphere. Therefore, exploration of aesthetic quality is perused through researching atmospheres of the houses, where sensory, bodily experiences are supported by visual ethnography to register and map the experiences.

Five sustainable single-family houses are subject to the field research as the researcher experiences living in each of the house throughout a couple of days. The registrations made are compiled into experience narrative reports and these form the basis for analyses. The analysis parameters origin from analyses of the Active House vision with focus on Environment, Indoor climate, and Energy, represented through nine parameters: Building typology, Harmoniously fit into landscape, Materials, View, Visual Privacy, Light space/spatiality, Filtration of light, Energy design (passive), Renewable energy design (active).

The results of the analyses are presented in a table format describing to what extend aesthetic quality are identified in each of the houses. It is concluded that aesthetic quality can be inherent in sustainable house if the design is approached intelligent in a holistic way where qualities of environment, indoor climate and energy are integrated.

# 1. Introduction

## Aesthetics as sustainability prerequisite

*'I think the most important thing a city has to have is beauty because if something is not beautiful or is not meaningful, people do not take care of it, do not develop responsibility – they forget about it.'* Thomas Sieverts<sup>1</sup>

According to German architect, urban planner and author Thomas Sieverts beauty is the prerequisite of sustainability because if there is not beauty people won't develop a relation that is meaningful for them to preserve and therefore not take care of their surroundings. Sieverts speaks of the city but his point is as valid for houses as well, as he speaks of the relation between human beings and their everyday surrounding environment. In this way Sieverts points to a very clear relation between sustainability and aesthetic or beauty as he calls it. Therefore, is important to create beautiful houses that people can develop relations to and take care of – a self-reinforcing effect– we take care of the beautiful surrounding environment and it will create beautiful and sustainable environments for us.

Despite Sieverts point sustainability in regards to houses is often reduced to compromise of economy and legislation. Legislative initiatives push forward the 'need to's' of sustainability influenced by lobbyism and vision while economy is the determining factor to which intentions are carried through. The decision to what aspects are vital enough not to be saved away should be based on a broad evaluation of aspects including qualitative aspects such as aesthetics and quality.

## Atmosphere as the new aesthetics in architecture

In 1993 German philosopher Gernot Böhme wrote the paper *Atmosphere – the New Aesthetics*<sup>2</sup> pointing to that beauty lie in the experience of atmosphere in the presence of objects and environments.

*'The new aesthetics is thus as regards the producers a general theory of aesthetic work, understood as the production of atmospheres. As regards reception it is a theory of perception in the full sense of the term, in which perception is understood as the experience of the presence of persons, objects and environments.'* Gernot Böhme<sup>3</sup>

Considering atmosphere the main aspect of architecture is a view shared by several architects and researchers nowadays. In her review on '*Atmosphere, aesthetics and quality through the eyes of architects and researcher's*<sup>4</sup> Olesen explores writing from Steen Eiler Rasmussen, Peter Zumthor, Juhani Pallasmaa, Florentine Sack and Steven Holl – all architects and teachers who circles around the concept of atmosphere. Literature by researchers in the field is also studied and it is all compiled in an analysis designating a range of imperative quality parameters.

*'Just imagine if the quality of our buildings were measured by their ability to improve life.'*

This is one of the motivational sentences behind the MIMA project<sup>5</sup> working with measuring quantitative and qualitative aspects of realised sustainable houses developed and built based on the Active House vision<sup>6</sup>. Through their paper *Measuring Sustainable Homes – a Mixed Methods approach*<sup>7</sup>

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<sup>1</sup> (Sieverts 2012)

<sup>2</sup> (Böhme 1993)

<sup>3</sup> (Böhme 1993)

<sup>4</sup> (Olesen 2013)

<sup>5</sup> (Olesen 2011f)

<sup>6</sup> (Sloth 2010)

<sup>7</sup> (Olesen et al. 2011)

Gylling et al develops a list of *What parameters to measure* in sustainable houses and also compiles a range of methods for the purpose of measuring these<sup>8</sup> (fig. 1).

**Figure 11: QUALITATIVE PARAMETERS: What parameters to measure<sup>9</sup>**

Energy design: <ul style="list-style-type: none"> <li>• Design</li> <li>• Comfort</li> </ul>	Light: <ul style="list-style-type: none"> <li>• Viewout</li> <li>• Visual privacy</li> <li>• Visual comfort</li> <li>• Individual control</li> <li>• Dark bedrooms at night</li> </ul>	Resources and emission: <ul style="list-style-type: none"> <li>To be defined in future process</li> </ul>
Natural design solutions: <ul style="list-style-type: none"> <li>• Design</li> <li>• Comfort</li> </ul>	Thermal environment: <ul style="list-style-type: none"> <li>• An intuitive human interface</li> <li>• Draught</li> <li>• Natural ventilation paths</li> </ul>	Characteristics and culture: <ul style="list-style-type: none"> <li>• Regional building typology</li> <li>• Regional functional tradition</li> <li>• Potentials and constrains in local climate</li> <li>• Regional materials</li> <li>• Harmoniously fit in landscape</li> <li>• Impact on street- and landscapes</li> <li>• EIA</li> <li>• Preservation of existing values</li> <li>• Ecological quality of the site</li> <li>• Risks by climate changes</li> </ul>
Renewable energy: <ul style="list-style-type: none"> <li>• Design</li> </ul>	Indoor air quality: <ul style="list-style-type: none"> <li>• Individual control</li> <li>• Low-emitting building materials</li> </ul>	
	Acoustics: <ul style="list-style-type: none"> <li>• Acoustic privacy and quietness</li> </ul>	

Aesthetics, beauty and atmosphere are introduced as important terms and approaches to describe qualities in sustainable architecture. Through this paper these aspects will be explored through field study research in five sustainable dwellings. The field research consist in sensory experiences supported by photography is compiled into experience narrative reports that form the basis for analyses.

## Article hypothesis and research questions

This paper seeks to explore how quality aspects of sustainable houses can be identified, measured, registered and analysed. The paper work with the hypothesis that sustainable houses must contain aspects of aesthetic quality, because sustainability cannot be achieved solely by technical and passive means, but is a holistic matter of integration of technical, health related, social, and aesthetic aspects.

By analysing quality parameters measurement of aesthetics and quality in sustainable house is be approached, why securing aesthetic aspects and quality in sustainable houses is of imperative means for cultivating sustainability of the house – following Sievert’s hypothesis that beauty is a prerequisite for sustainability.

## Research questions

*What methods in field studies can be used to approach measuring aesthetic quality in sustainable houses?*

*How can a sensory approach support identifying aesthetically qualitative aspects in sustainable houses?*

*What can the parameters say about aesthetic quality in sustainable houses through analyses?*

The paper will focus on a few aspects through the analyses but will attempt to discuss and conclude in a more general sense. The paper aims at exploring parameters to capture the quality of sustainable houses and the analysis are based on experience reports on all house compiled on basis of field research.

<sup>8</sup> (Olesen et al. 2011)

<sup>9</sup> (Olesen et al. 2011)



## 2. Methods and methodological approach

Through this chapter the approach to field research and the methods applied to data collection will be presented and described; respectively sensory experience studies, experience and registration photography and the compilation of data into a visually supported descriptive experience narrative.

### Field research

Field research is about going out in the field with the purpose of collecting data employing variable methods such as direct observation, participation studies, analyses of personal documents, self-analysis; methods which are often characterized as qualitative but also may include quantitative aspects. In the classical understanding the methods are anchored mainly in the ethnographic and anthropological sciences – sciences that study people and cultural phenomena. In this case, the area subject to research is the sustainable houses.

*‘Doing field research is a unique and personal experience. While different ethnographers may purport to use the same methods, they will in fact do so indifferent ways.’ Sarah Pink<sup>10</sup>*

The field research will focus on exploring the sustainable houses and its behavior and cultural phenomena; this for instance be the relation between the house and the surrounding nature, the interplay between the houses materials, or maybe the narratives in the way the daylight with is accompanying shadows enter through the skylights.

### Sensory experience

In 1969 Danish architect Steen Eiler Rasmussen’s book *Om at opleve arkitektur*<sup>11</sup> (Experiencing architecture) presents a sensuous approach to architecture and call for to go out and see and sense architecture where it is instead in trying experiencing it by reading about it. This literary work has become part of the fundamental training for every student of architecture.

*‘For even the most meticulous description of enumeration of all visible properties would not give us any idea of that we can feel as significant by the overall impression. Just as you do not read the individual letters of a word, but receives an overall idea of the concept the word covers; so, you don’t know in general what you sense, only the notion that occur as a result of sensing.’ Steen Eiler Rasmussen<sup>12</sup>*

In 2005 Juhani Pallasmaa’s book *The Eyes of the Skin*<sup>13</sup> pick up Eiler Rasmussen’s approach and argue for the importance of bodily and sensuous confrontations rather than reduction to visual observations.

*“Architecture is usually understood as a visual syntax, but it can also be conceived through a sequence of human situations and encounters. Authentic architectural experiences derive from real or ideated bodily confrontations rather than visually observed entities.” - Juhani Pallasmaa<sup>14</sup>*

Pallasmaa further points to the primary task of architecture: to make us experience ourselves as complete human beings.

*“The sense of self, strengthened by art and architecture, allows us to engage fully in the mental dimensions of dream, imagination and desire. Buildings and cities provide the horizon for the understanding and confronting of*

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<sup>10</sup> (Pink 2007)

<sup>11</sup> (Rasmussen 1989) Quote translated by author.

<sup>12</sup> (Rasmussen 1989 p32)

<sup>13</sup> (Pallasmaa 2005)

<sup>14</sup> (Pallasmaa 2005)

*the human existential condition. Instead of creating mere objects of visual seduction, architectural relates, mediates and projects meanings. The ultimate meaning of any building is beyond architecture; it directs our consciousness back to the world and towards our own senses of self and being. Significant architecture makes us experience ourselves as complete embodied and spiritual beings. In fact, this is the great function of all meaningful art.'* Juhani Pallasmaa<sup>15</sup>

Both Eiler Rasmussen and Pallasmaa argue for the experience of architecture to takes place in bodily or sensuous perception atmosphere. How can this sensuous approach be conducted in research with the purpose of collecting usable data?

*'For the purposes of this kind of research the only reliable instruments of observation are the human senses.'* Dean Hawkes<sup>16</sup>

Sense organs are specialized parts of the nervous system that detect - conscious and unconscious - what's going on in the body and its surroundings. Sensory impressions include light, sound, orientation in space, smell, taste, pain, cold, pressure and touch. Each sense has its organ; for instance is the sense of light handled by the eye and the sense of sound and orientation by ear. Both eye and ear are genuine organs. The other senses are handled by special nerve fibers and are (except smell and taste) generally spread to larger parts of the body. Sensory impulses to the brain provide information on what action is to be created. The pulses go to the entire nervous system, the cerebellum and cerebrum, so people can see and talk and move appropriately. All sensory impressions and information from the senses and the outside world goes to the central nervous system. The individual sensory impression is thereby integrated to perceive the whole.



**Picture 1 Eye, ear, nose and hand representing the human senses**

*'The body and its perception skills are fundamental. Our bodies understand space, surroundings, and environment. The body has sensory experience, because we like all mammals mobilize all our instincts. Our body is infinitely alert ... We come into a room, we feel - our body senses - if there are others in the room. We do not see it, we do not hear it, we do not smell it, but our body understands it right away. Much of our experience is the experience of our body.'*<sup>17</sup>

Fundamental to the perception of architecture are all the senses and the overall impression they create, however, is tactile, vestibular and kinesthesia senses are special as these can be related to the actual physical interaction with the building materials and surfaces. The sense of tactility, touch, affects registration of cold and heat, precision movements and physical and social contact with others. The vestibular sense is related to the body's labyrinth organs that detect gravitational movements and the sense is important for eye movements, speech and brain readiness. The kinesthetic sense is the sense of

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<sup>15</sup> (Pallasmaa 2005 p11)

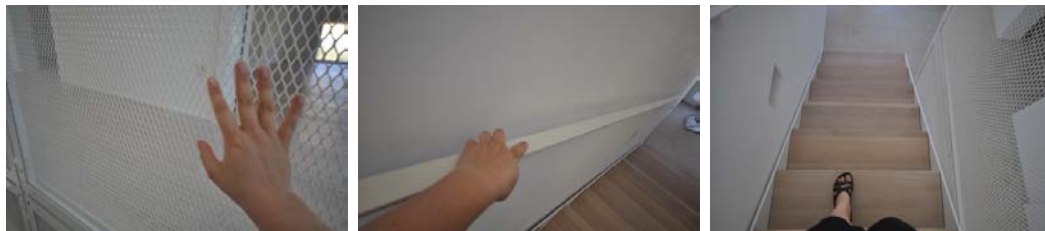
<sup>16</sup> (Hawkes 2008)

<sup>17</sup> (Guttormsen, Bertelsen 2003) Quote translated by author.

touch for muscles and joints and provides information on where the body is in relation to gravity and where the individual body parts are in relation to the body and the sense affects the precision of movements, body awareness, balance, vision in a room and rhythm.<sup>18</sup>

*'Every significant experience of architecture is multi-sensory; qualities of matter, space and scale are measured by eye, ear, nose, skin, tongue, skeleton and muscle.'* Juhani Pallasmaa

Measuring with senses is the headline for conducting the field studies in the houses.



**Picture 2: Pictures from authors sensory experiences of one of the sustainable houses subject to research**

### Experience and registration photography

Photography has a long and varied history in ethnography. Supported by different methodological paradigms, a camera has been an almost mandatory element of the 'tool kit' for research for several generations of ethnographers<sup>19</sup>. To support the immediate sensuous experiences of the house photography will be used to capture experiences, map situations and support memory.

*'Any experience, action, artifact, image or idea is never definitively just one thing but may be redefined differently in different situations, by different individuals and in terms of different discourses. It is impossible to measure the ethnographicness of an image in terms of its form, content or potential as an observational document, visual record or piece of data. Instead, the ethnographicness of any image or representation is contingent on how it is situated interpreted and used to invoke meanings and knowledge that are of ethnographic interest.'* Sarah Pink<sup>20</sup>



**Picture 3: Pictures of cameras in the houses during field studies – experience and registration photography**

### Experience narrative report

Sensuous experiences and photography will together be compiled into experience narrative reports describing the field studies of each of the houses including a narrative of encountering the house, a visual room by room description, an Active house parameters narrative, time-lapse study

<sup>18</sup> (Sørensen, Kløve & Skole 2009)

<sup>19</sup> (Pink 2007 p23)

<sup>20</sup> (Pink 2007 p23)

investigations and luminance mapping studies. The following analyses are based on experience narrative reports<sup>21+22+23+24+25</sup>.

### Field research subjects: five sustainable houses

The Active House vision<sup>26</sup> and intentions has resulted in realization of a number of sustainable building projects. As part of their strategy to take an active role in developing sustainable buildings leading roof window company VELUX A/S initiated the large-scaled project ModelHome 2020 ‘a vision for climate-neutral buildings with a high level of livability’<sup>27</sup>. In this way of thinking and developing concepts the projects Home for Life, LichtAktiv Haus and Sunlighthouse are designed and built as part of the Model Home project. Haus der Zukunft and Solaraktivhaus are initiated by solar heating company SONNENKRAFT<sup>28</sup> and are also inspired by the Active House vision.

**Tabel 1: Presentation of the sustainable houses in the field research study**

	HOME FOR LIFE <i>Lystrup, Denmark</i>	HAUSDERTZUKUNFT <i>Regensburg, Germany</i>	SOLARAKTIVHAUS <i>Kraig, Austria</i>	LICHTAKTIVHAUS <i>Hamburg, Germany</i>	SUNLIGHTHOUSE <i>Pressbaum, Austria</i>
South façade					
Vest façade					
North façade					
East façade					

### 3. Analysis of aesthetic quality in sustainable houses

The sustainable houses are analysed through the present chapter. Through the analysis examples of various works of architecture experienced by main author are presented as to illustrate and elaborate

<sup>21</sup> (Olesen 2011b)  
<sup>22</sup> (Olesen 2011a)  
<sup>23</sup> (Olesen 2011d)  
<sup>24</sup> (Olesen 2011c)  
<sup>25</sup> (Olesen 2011e)  
<sup>26</sup> (Sloth 2010)  
<sup>27</sup> (VELUX A/S 2013)  
<sup>28</sup> (SolarCAP 2010)

each parameter<sup>29</sup>. The parameters analysed are chosen from the list of parameters given in fig. 1 to touch upon experienced aesthetics and quality in environment, indoor climate and energy.

## Aesthetic quality in environment

Aesthetic quality in the environment has to do with how the house relates to its surroundings, is shaped and oriented with regards to weather conditions, fitting into land- and streetscapes and expression of materials.

## Building typology

Building typology of houses ranges widely and many different examples can be given, however, the most commonly used typology is a gable, a flat or a lean-to roof (pic. 4). When the task is to develop the house for optimized renewable gains the classic typologies are challenged.

All of the sustainable house have sloped roofs for harvesting sun energy and light. LichtAktiv Haus is the simplest shaped like a rectangular box with lean-to roof while Sunlighth is the most complex with several different volume shapes and roof slopes. Generally there seems to be a tendency of designing more to match the saltbox typology and its advantages of different expression, when integrating technology for energy and light gain.

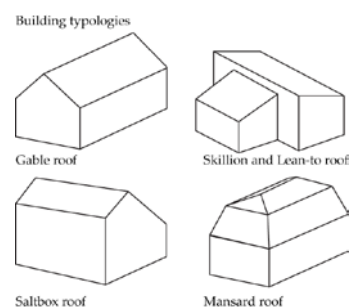
## Harmoniously fit into landscape

Relating the house to the landscape is a way aesthetically cobbling the house to the place. Zumthor's tiny wooden Kapelle (pic. 5) calmly sits on a sloped mountain leaning back and over viewing the valley, like it just belongs there, while Zaha Hadid's extension to Ordrupgaard (pic. 6) wiggle through the landscape standing out in a dark concrete shape yet relating to the place by mirroring the surrounding woods is miming the area.

The landscapes surrounding the sustainable houses are quite modest – for most of them at least, as these are more or less merely placed on to the site and oriented to the best solar gain direction and view. Sunlighthouse, how every has really beautiful landscape and its architecture provides both intimate the magnificent views (table 2).

## Material

Materials create signals or stories of the building. Wood will often provide impressions that create natural, soft and warm feelings (pic. 8), while stone often is perceived as cold and hard; though they are both carved out of nature. 'New materials' central to the sustainable houses are different types of energy technologies, as solar hearing and Photo



Picture 4. Building typologies



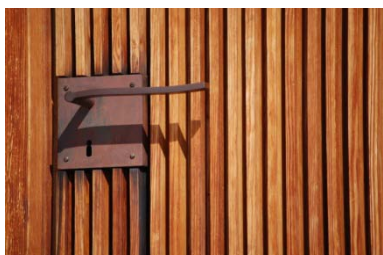
Picture 5. Saint Benedikt Kapelle, Zumvigt, Schweiz by Peter Zumtor



Picture 6. Ordrupgård, Extension to Museum, København, Zaha Hadid



Picture 7. Forum Building, Barcelona, Spain, by Herzog & de Meuron



Picture 8. Wood cladding and rust door handle. Saint Benedikt Kapelle, Zumvigt, Schweiz by Peter Zumtor

<sup>29</sup> (Olesen 2013)



Voltaic panels, as these with their shiny, glistening, and reflecting surfaces (pic. 7) begin replacing other materials.

The houses all have wooden, grayish and blue (technologies) colors – supplied by the blackish, blank reflecting window – creating expressions of small machines. Haus der Zukunft, Solar Aktivhaus, and LichtAktiv Haus seems a bit doll in choice of materials while the more golden wood colors in Home for Life and Sunlight provides a more pleasing expression (table 2).

**Tabel 2: Analysis scheme – Aesthetic quality in relation to environment parameters**

	HOME FOR LIFE Lystrup, Denmark	HAUSDERZUKUNFT Regensburg, Germany	SOLARAKTIVHAUS Kraig, Austria	LICHTAKTIV HAUS Hamburg, Germany	SUNLIGHTHOUSE Pressbaum, Austria
Building typology	 <p>Inspired by classic single-family house shed roof typology but the top of the roof is pushed north – increasing area of the south-facing roof for renewable energy technology.</p>	 <p>Shape describes as diamond inspired. Shaped accordingly with optimal positioning towards solar energy gains. Shape has similarities to a mansard roof shape.</p>	 <p>The form is a merger between a squared box and a shed-roofed shape. South roof slate for energy production while the profile has a harsh and pointy look.</p>	 <p>The old Setteler's house has its original shape. The new part is a simple rectangular shape lifted in the one side to make slate for energy production – a modernistic look.</p>	 <p>Roof surfaces are tilted in different directions in consideration of solar energy gains, daylight intake and the shape of spaces inside.</p>
Harmoniously fit into landscape	 <p>The dwelling sits on the top of the bake the roads leads up to. It seems to be leaning back, relaxing (maybe even sunbathing) and enjoying the view of the bay.</p>	 <p>The dwelling sits flat on the ground in front of a double storey row-housing. In front of it there is a thin chain of trees covering a railway with trains passing every 10-15 minutes.</p>	 <p>The profile of the building provides the impression that the building was dropped onto the landscape. Geometry of building seems off in some way.</p>	 <p>Existing part of the building fit of course into area. The new part is smaller and very simple and thereby fit into area by not dominating or standing out too much.</p>	 <p>The pale north façade faces the quiet street and is cut off to follow the soft hill shape. Dimension of the building seems to fit into the place and converses with the neighboring dwellings.</p>
Material	 <p>Wood construction and the wooden floors are local (Danish) whereas the slate façade materials have travelled from Switzerland.</p>	 <p>Wood construction with Eternit tiles – all in steel, grey and blue nuances creating a machine-like look.</p>	 <p>Clad with longitudinal light wooden planks on all exterior surfaces except South which is clad Eternit panes</p>	 <p>Exposed construction in whitewashes pine clad with glass pane (translucent), steel lamellas and energy technologies Materials strand out in the area.</p>	 <p>Wood construction clad with thin vertical wooden lamellas in varying dimensions.</p>

## Aesthetic quality in indoor climate

Aesthetics of indoor climate has to do with what qualities are experienced in and from indoor spaces. View and visual privacy are parameters focusing on relations between house and its surrounding environment and how these are experienced in relation to the design expression. Light can provide various experiences of quality, such as illuminating surfaces, creating shadow/light contrasts, and telling narratives of time as light and shadows moves around the spaces through the course of day.

### View

View can be treated quite differently in architectural design from intimate and enclosed to wide, magnificent and open. Japanese architecture work with architecture and nature as one entity where nature is framed like a scenery to provide special/directed experiences and feelings in the adjoin spaces in a very near and intimate setting (pic. 9). In his Experimental Summerhouse Aalto creates a directed, framed, magnificent view by using the nature's pillars of the forest to lead the view to the lake (pic. 11).

Due to their different locations the houses work with different kinds of views. Haus der Zukunft and Sunlight both establishes an intimate view into the treetops with a rich, natural, colourful and live sense to it. LichtAktiv Haus created a private view into the garden and create a feeling of both intimacy and spaciousness. Both Home for Life, Solar Aktivhuas and Sunlihouse have farsighted views – the last one is the most amazing.

### Visual privacy

Visual privacy is closely related to transparency and is therefore an interesting parameter in relation to these sustainable houses as window areas are significantly increased compared to typical houses. Transparency is highly related to the degree of privacy one feels in a space. The closed stone and water terrace year in Mies van der Rohe's Pavillion is a space that is completely closed off from outside views and is only open to the sky, providing a feeling of a meditative and inward space (pic. 12). The opposite is the case in the VM housing complex where glass facades entirely exhibit the life unfolded in its exposed spaces (pic. 13).

All of the sustainable houses have large floor to ceiling windows exposing especially south facing spaces. Due to its location surrounded by roads Home for Life is the most exposed spaces where both kitchen and living room are completely exposed – especially at night. The remaining houses also have large transparent facade areas but as these



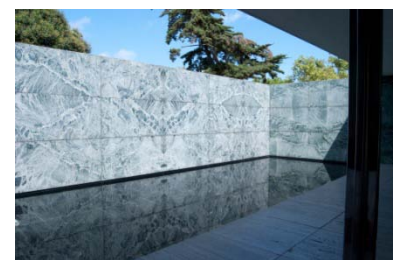
Picture 9. Tea-room, Kyoto, Japan



Picture 10. Architect's own house, Brabrand, Denmark, by Knud Friis



Picture 11. View from Alvar Aalto's Experimental Summerhouse, Muuratsalo, Finland










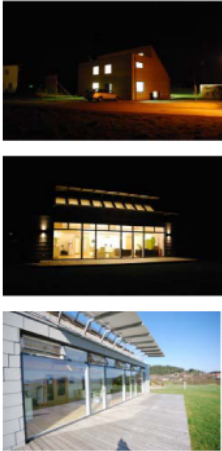
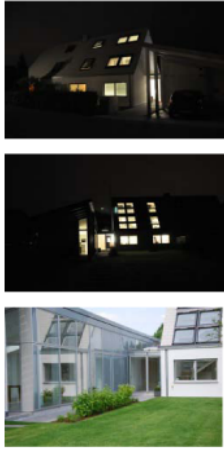

Picture 12. Pavillion, Barcelona, Spain, by Mies van der Rohe



Picture 13. VW housing, Ørestad, Copenhagen, by BIG

are not facing trafficked roads, this is not experienced as an issue. The possibility to screen, however, is experienced as very important for creating privacy – because looking into the black reflecting inside of window surfaces in the dark can create the insecure feeling that you might be watched.

**Tabel 3 Analysis scheme – Aesthetic quality in relation to indoor climate parameters View and Visual privacy**

	HOME FOR LIFE Lystrup, Denmark	HAUSDERZUKUNFT Regensburg, Germany	SOLARAKTIVHAUS Kraig, Austria	LICHTAKTIV HAUS Hamburg, Germany	SUNLIGHTHOUSE Pressbaum, Austria
View	 <p>From the kitchen there is a view over the rooftops to the bay – the view is even better from the upstairs spaces and terraces.</p>	 <p>From the upstairs hall there is an amazing view into the green, soft, wavy tree tops – this creates a sort of velvet backdrop giving the space a feeling of nearness to nature.</p> <p>The trees are also visible from the downstairs spaces.</p>	 <p>From the living room space the floor to ceiling windows creates a view of flat green fields with chains of mountains in the far background.</p> <p>From the gallery on the top floor it is rather difficult to get a view out of the row of skylights.</p>	 <p>Garden facing spaces has a pleasant view into a little oasis. Sitting in the roofed outdoor space nature feels very present and creates a calm feel.</p> <p>From the library there is a nice view of the garden</p>	 <p>To the South-West spaces on all floors have a stunningly pleasant view into the green tree tops.</p> <p>In living room there is a great view to the West; landscape and sporadic roofs.</p>
Visual privacy (look into the house)	 <p>Seen at night from the road in front of the house where people pass by the location unfortunately allows great opportunities for insight when the garden is not closed with vegetation.</p>	 <p>The dwelling is turning its back to the road and driveway and opening up to the green on the south side. The interior spaces seem very private.</p>	 <p>The building almost creates an image of a display façade in a store and there are not curtains, but the façade is facing nature so no one will pass by.</p>	 <p>Placed only meters from the pavement windows in the old part are exposed. The new addition turns its back to the road and embraces the space created between the old and new parts.</p>	 <p>From the road it is possible to see only into the kitchen and the wind catcher in front of the entrance to the house. The house is situated at the almost-end of the road so not many people are passing by.</p>



## Light

The parameter light is not elaborated in the scheme so the understanding of light is based on authors sensuous experiences and can be separated into (among other) Light space/Speciality and Filtration of light.

### Light space/Spatiality

Light space or spatiality covers the experience of space filled with light preferably from different directions playing with shapes, materials, protrusion, indentations, and rhythms of the space and are ever-changing in intensity, nuances, and colors. Light spaces can carry enormous presence and create bodily experiences. The labyrinth hall in Louisiana creates an open yet intimate and calm light space simply consolidating materials, surfaces, structural rhythm nature and light (pic. 14). The intimate Kapelle in Zumvigt is a small enclosed, self-embracing space softly lit from the window band, a light space with immense presence and glow (pic. 15).

The houses have very different light spaces – and some of them are quite amazing to experience. Especially the hall space of Sunlighthouse is breathtaking and creates a thorough bodily experience. The Solar Aktivhaus don't really have a light space and thereby lack the captivating aspect where body and mind are aesthetically pleased.

### Filtration of light

Filtration of light can be one of the effects of light space but can also stand on its own feet. It is the buildings way of playing with the sun leaving imagery-like shades on the surfaces of the building. The effects filtration of light creates and the impressions and narratives it tells can form immense sensuous quality. The amazingly organic and landscape-like ROLEX building (pic. 16) is covered by glass all facades and when sun screening is needed vertical curtain lamellas drop down in front of the glass and filters light onto the light interior spaces, creating quite amazing effects. In Koldinghus the old multi-bar-windows draw shadow lines and squares in the floor and the meeting with the floor material rhythmic pattern strengthens the feeling that the sun is exploring the building (pic. 17).

The houses filter light in very different ways. In some, for instance Sunlighthouse, you have to search for this effect, while in others, for instance LichtAktiv Haus, it is hard to miss. The best examples are found in the LichtAktiv Haus where respectively the PV patches outside and the steel-net in the staircase weld creates intriguing effects. Shadow patterns can be amazing to watch and explore as they stiflingly intensify and dim on the surfaces they strike.



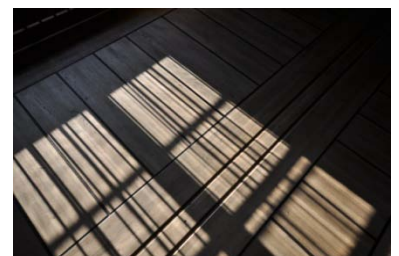
Picture 14. Louisiana Museum of Modern Art, Humlebæk, Denmark, by Bo and Vohler Architects



Picture 15. Saint Benedikt Kapelle, Zumvigt, Schweiz by Peter Zumtor

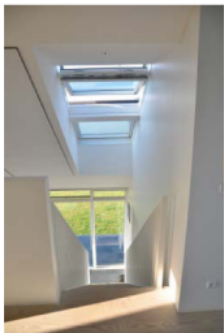

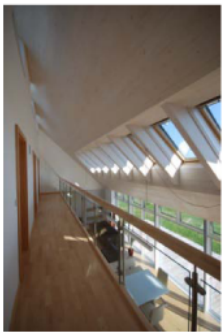
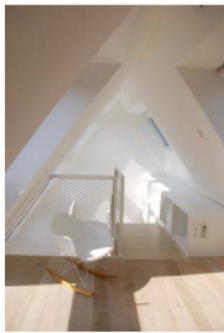

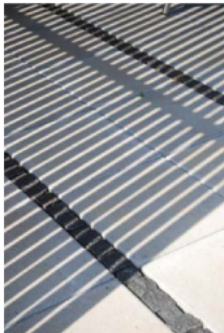





Picture 16. ROLEX Building, Lausanne, Schweiz, by SANAA



Picture 17. Koldinghus, Kolding, Denmark, by Inger & Johannes Exner

**Tabel 4 Analysis scheme – Aesthetic quality in relation to indoor climate parameters Light space/Spatiality and Filtration of light**

	HOME FOR LIFE Lystrup, Denmark	HAUSERZUKUNFT Regensburg, Germany	SOLARAKTIVHAUS Kraig, Austria	LICHTAKTIV HAUS Hamburg, Germany	SUNLIGHTHOUSE Pressbaum, Austria
Light space / Spatiality	 <p>Light spaces are created all around the dwelling – not two spaces are alike in their anatomy and they all have windows placed differently. For instance the kitchen has light coming from the South- and East-facing façades, the glass entrance to the North.</p>	 <p>Standing under the double-high space one feels so many different moods at once – direct and diffuse light in golden and blue colors melt together at creates a light and rich atmosphere.</p>	 <p>The general impression of the spaces in the house is that it is rather diffuse and the many wooden surfaces and white walls seem to shyly blend and become rather anonymous.</p>	 <p>The covered terrace is an outdoor light space created as the sunlight falls through the PV patchwork and paints shadows in the space.</p> <p>The top floor library also has amazing light space quality where hard and soft light from the skylights blends into a rich whole.</p>	 <p>The upstairs hall in THE light space of the dwelling. It's narrow space is visually elongate by the rays of light falling on the light pine panels in the interior spaces creating a rhythmic feel. Diffuse light from the glass panes above the spaces provides a light openness.</p>
Filtration of light	 <p>The wooden lamella sunscreen can manually be moved to create shelter from wind and curious looks and simultaneously its pattern draws rhythmic shadows on the stone flooring of the terrace space.</p>	 <p>The silver like steel lamella curtains automatic runs down when the sun is sharp or the temperature too high. Individual lamellas tilts according to sun position and draw shadow patterns.</p>	 <p>The effect is not present in the house – in fact there are no curtains or adjustable shading at all... Only the window frames roughly filters the light leaving long lines of shadows on the floors.</p>	 <p>Wire mesh as shielding the staircase creates small square patterns on the wooden steps and around the interior space.</p>	 <p>There is not much filtering effect – only the thinly sliced voids in the shielding panels alongside the stairs filters the light and leaves small beams of light in the dim staircase to the basement.</p>

## Aesthetic quality in energy

Primarily, energy is considered a quantitative parameter, however, the qualitative and aesthetic aspects of what an energy optimized design bring to the building are central for the perception of it.

### Energy design

Energy design is a parameter telling something about how the passive design of the house has been optimized to be as energy sufficient as possible prior to application of active technologies; for instance by compactness of building volume and orientation towards the sun (pic. 20). Passive houses are examples of buildings working with this approach only and the Danish project Komforthusene in Vejle show examples of how the strategy can be expressed in a design (pic. 18).

All the houses are shaped to optimize their form with regards to utilizing the availability of renewable energy onsite. The roofs are sloped for best possible solar energy gain – Home for Life in Denmark is the lowest slope and Haus der Zukunft in Regensburg in the Southern Germany has the steepest roof-surface. Aesthetically this creates very different expressions but they all tell stories of energy.

### Renewable energy design

Renewable energy technologies can create an expression of energy conscious behavior or provide an impression of something futuristic. They can be used intelligently and be integrated in the design to create beautiful surfaces, or applied poorly and thereby create visually clumsy buildings. The 'material' is rather new in building design and architects experiment with it. In Økohouse 99 (pic. 19) the solar panels substitutes façade cladding and becomes a physically and visually well integrated part of the design. The yellow house in London (pic. 21) exemplifies the opposite where the renewable panels are seemingly just laid on top of the tall building.

Solar heating panels, Photo Voltaic panels and skylights are integrated in all of the houses roof designs creating different expressions and feelings of energy conscious and futuristic houses. In Home for Life there is a nice play in the surface of ruffled slate, technology panes and skylights. Haus der Zukunft seems almost entirely wrapped in technology when looking at it from the garden side – creating an expression of a landed spaceship. LichtAktiv Haus and Sunlighthouse also provides impressions of whole solutions to the integration of renewable, whereas Solar Aktivhaus differ by adding the renewable onto the roof rather than into the roof and by applying these dark panels to a light roof surface.



Picture 18. Stenagervænget 28, Comfort house, Vejle, Denmark, by Jordan + Stenberg



Picture 20. Økohus 99, Skejby, Denmark, by Vandkunsten



Picture 19. Passive row-housing, Lystrup, Denmark, by Smidt, Hammer & Lassen Architects



Picture 21. House, London, Great Britain, architect unknown



**Tabel 5 Analysis scheme: - Aesthetic quality in relation to energy parameters Energy design and Renewable energy design**

	HOME FOR LIFE Lystrup, Denmark	HAUSDERSZUKUNFT Regensburg, Germany	SOLARAKTIVHAUS Kraig, Austria	LICHTAKTIV HAUS Hamburg, Germany	SUNLIGHTHOUSE Pressbaum, Austria
Energy design (passive)	 <p>The shape of the house is optimized for energy reduction and application of renewable. The many windows shall reduce electricity consumption for light.</p>	 <p>The volume is rather compact and seems to have been softly altered to create surfaces for energy technology. North side is very plain and passively boring while the south is interesting.</p>	 <p>The design of the building seems to have had strict energy reduction purpose with its compact rectangular shape and a minimum of windows to three sides it provides a kind of uninviting expression.</p>	 <p>The new part is shaped as a strict rectangular shape with a slightly sloped roof. This could sound boring, but its integrated coved carport and terrace and the shift in materials and surfaces actually makes it rather intriguing.</p>	 <p>The volume is cultivated to fit into the slanted plot – roof surfaces are sloped for different purpose and outdoor spaces are carved out. The facade facing the road is nicely proportioned while the opposite façade seems many times larger yet still relating to the place; appropriate for facing great nature.</p>
Renewable energy design (active)	  <p>Renewable technologies are all placed on the large South-facing roof surface and the thin blue-grayish shimmery nuances nicely relates to the ruffled grey slate.</p>	  <p>The diamond-shaped building corresponds very nicely with the shimmery PV and solar plated surfaces.</p>	  <p>Solar panels are added onto the top of the roof in a line while PV panels are added on stands. The idea is that the angle on the PV is optimized for solar gains while also creating shade for the skylights; it just looks confusing</p>	  <p>The patchwork-ish impression of the PV patches on the roof and covered outdoor spaces of the new building is an elegant way of integrating technology and simultaneously making ornament.</p>	  <p>The two sloped roofs are covered with solar panels, PV panels and skylights providing the impression that they are reaching for the sky to get even closer to the sun.</p>

## 4. Results: Aesthetic quality in sustainable houses

The below scheme presents a summarized result of the analysis indicating to what extent the proposed and explored aesthetics and quality parameters can be identified in the respective houses. Home for Life and Sunlighthouse both score relatively high on the chosen quality parameters, while Haus der Zukunft and LichtAktiv Haus range just after and Solar Aktivhaus scores quite poorly.

**Figure 12. Results scheme of aesthetic quality parameter analyses:**

	HOME FOR LIFE Lystrup, Denmark	HAUS DER ZUKUNFT Regensburg, Germany	SOLARAKTIVHAUS Kraig, Austria	LICHTAKTIV HAUS Hamburg, Germany	SUNLIGHTHOUSE Preßbaum, Austria
Building typology	X	X	%	X	X
Fit into landscape	X	%	%	X	X X
Materials	X X	X	%	X	X X
View	X	X	X	X	X X
Visual privacy	% %	X X	%	X	X X
Light space	X	X	%	X X	X X
Filtration of light	X	X X	%	X X	%
Energy design	X X	X	%	X	X X
Renewable energy	X X	X X	%	X X	X

% % = No quality identified | % = Nearly no quality identified | X = Some quality identified | X X = Very much quality identified

## 5. Conclusion

*What methods in field studies can be used to approach measuring aesthetic quality in sustainable houses?*

The sensory experience approach has proven valid for gathering information on aesthetics and quality aspects of the houses and photos are a good media for capturing different aspects and transmitting them. The analyses show that there are in fact various aesthetic qualities in sustainable houses.

*How can a sensory approach support identifying aesthetically qualitative aspects in sustainable houses?*

The sensory exploration based approach paired with many photos has permitted empathetic descriptions of experience the houses providing insights into the spaces and details of the houses that are not possible to imagine based solely on images from the house. Sensuous bodily approach is vital in experiencing quality.

*What can the parameters say about aesthetic quality in sustainable houses through analyses?*

The chosen parameters have illustrated a wide range of aesthetics and quality aspects and how these can be explained and presented. Awareness of the various parameters during field research is imperative.

Aesthetic quality can be inherent in sustainable house if the design is approached intelligent in a holistic way where qualities of environment, indoor climate and energy are integrated.

## 6. Discussion

When writing and talking about sustainable architecture the discourse seem to automatically turn to technical and material aspects - maybe because these aspects are quite logical and tangible to comprehend and discuss? When the discourse turns to more qualitative aspects such as aesthetic the discussion becomes more difficult to grasp – maybe because the concepts here are more complex and uneasy to define, describe and discuss? But, is possible to create a kind of conceptual framework, to make these qualitative aspects easier to discussable, or maybe even equate the qualitative discourse with the quantitative?

### Aesthetic quality in sustainable houses

Intelligent and sensuous architects, such as Alvar Aalto, Steven Holl and Peter Zumthor, have the ability to create inherent aesthetic quality in the atmospheres of their architecture that add that special something that is so breath taking and overwhelming, that your body feels the desire to go back and experience more. This aspect of aesthetic quality is desirable for all kinds of buildings; and especially for our homes where we spend most of our time. So, the question here is what challenges do the increasing demands of sustainable technology, energy reduction and indoor climatic conditions cause for aesthetic quality? Is aesthetic quality neglected in the process of achieving the optimized technical house or can sustainability be turned to an advantage in cultivating aesthetic quality in houses?

### Sensory experiences of atmospheres

The analyses carried out through this paper provide some answers to the questions posed above. For instance in the case of LichtAktiv Haus, where intelligent integration of photo voltaic, not in their original panels shape but as small leaf patches create the most amazing spacious effects as the sunlight is filtered through and establish a feeling of sitting in the shade under the branches of a big tree in the forest. This feeling that the photo voltaic belong in the sensuous space is exactly the kind of integration desirable in creating holistic sustainable buildings. The creation of a house with its functionality and technical means must all come together in one to form the spaces we live in. How these aspects are valued and are a matter of how they relate to the body and create bodily experience. Atmosphere does not live in the individual elements but in the merging between and the experiences of the elements.

### Judging atmospheres and aesthetic quality

An aspect of exploring and explaining aesthetic quality is describing the experienced aspects and thereby making it possible to judge what for instance a view or an integrated PV panel is worth – aesthetically – an aspect not usually touched on in judging of sustainable houses. The results of the analyses are presented in a table format where valuations of the respective parameters are deducted to quantitative representative values. The intention behind this is to create a valuation discourse for the qualitative aspects that can be equated to the quantitative ones. Is this sterile representation a valid way to represent aesthetic quality? Or should we maybe look at raising the level of qualitative aspects in the representation of quantitative valuation of sustainable houses?

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*All photos in the paper are taken and composed by author*





## Measuring Sustainable Homes – A Mixed Methods Approach

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*Conference theme: On Measurement*

*Keywords: Measuring, sustainable, homes, Mixed Methods*

# Measuring sustainable homes

## - a Mixed Methods approach

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**ABSTRACT:** The paper studies the *Active House vision* and the *Active House Specification work-in-progress* to identify *what* parameters to measure when measuring sustainable homes of the future. The approach is based on a Mixed Methods research strategy where measurements are related to both quantitative and qualitative aspects in relation to the categories Energy, Indoor climate and Environment. The *what to measure* part of the paper results in a matrix that lists the measurement parameters. On basis of the measurement parameters a set of methods are compiled into a matrix that defines *how to measure* regarding quantitative and qualitative aspects. These methods imply Logging and data handling in Excel, Luminance mapping, Cultural Probes, Semi-structured Interviews, Observation, Self-experience studies and photo registration. The paper presents two matrices on *what* and *how* to measure sustainable homes. The paper is concluded with the assumption that exploring seven experimental sustainable homes will result in knowledge and learning to develop a holistic assessment method for evaluation sustainable homes of the future.

Conference theme: On Measurement

Keywords: Measuring, sustainable, homes, Mixed Methods

# 1. INTRODUCTION

Focus on development of sustainable architecture is at an ever high. This has resulted in eagerness to prove the performance of buildings resulting in an increase of rules, evaluation criteria and legislation bringing the tendency of gradually overlooking qualitative aspects while focusing on the quantitative and immediately measurable aspects (Birgisdottir, 2010). The tendencies bear witness to a paradigm shift in the ways of considering and studying sustainable living and sustainable homes – a tendency indicated by several recent research projects (e.g. Marsh et al 2010, Entwistle 2010, Brunsgaard 2011). According to Willars and Lynch (2010) the technical means only account for about 20 percent of solving the challenges, whereas occupants' behaviour and lifestyle can account for at about 80 percent. This underlines the importance of not ignoring the architectural and qualitative aspects related to experience, well-being and health and appoints to an approach based on occupants' needs and experiences.

With the new strategic initiative *Active House vision* attention is brought to a holistic approach to considering and developing sustainable homes of the future (Sloth 2010). The initiative is based on collaboration between the building industries, product companies and research institutions and carries the objective to create knowledge that develops holistic sustainable architectural solutions of the future.

The *Active House vision* has resulted in the development of a full scale experimental lab consisting of seven sustainable homes. This project makes it possible to measure these seven experiments through exploratory research in contemporary issues related to the paradigm shift providing possibility of

qualitative estimates for developing sustainable homes.

The main objective of the work is to design *a method for holistic evaluation of sustainable homes of the future*. The inclination to establish a holistic assessment method is to provide for a more balanced consideration when learning how to design and develop buildings of the future. Quantitative aspects typically represent the physical and technical – whereas qualitative aspects typically represent the social, psychological and philosophical environments surrounding us.

Based on systematic research the compilation of an evaluation method, that can substantiate and demonstrate a range of sustainable aspects, should lead to the composition of evidence supporting the need to consider buildings from a holistic perspective. Evidence can influence political debate and decision-making and thereby push for implementation of *both* quantitative *and* qualitative aspects in future strategies, evaluation models and legislation.

This paper addresses the problem of *what* and *how* we shall measure sustainable homes to extract knowledge with which to aim for a holistic approach of assessment.

## 2. What to measure in sustainable homes?

The purpose of the paper is to identify *what to measure* in order to compile data and information through measurement. Data and information is a necessity in order to analyze and identify *what parameters* are central to measure and evaluate. This implies the need for identification of what methods to use for measuring quantitative and qualitative aspects of sustainable homes. Through this paper we seek to verify what to measure through formulating the hypothesis that: *Through studies of the Active House vision and its coherent design*

*parameters we can identify what to measure through quantitative and qualitative aspects.*

Identification of what to measure will lead to the problem of *how to measure* the parameters. This paper attempts to verify the hypothesis that: *By compilation of methods from natural science and artistic and humanistic disciplines it is possible to design a frame on how to measure quantities and qualities in sustainable homes.*

To approach verification of the hypotheses this paper will study state-of-the-art research projects that work with measuring sustainable houses. The projects take a Mixed Methods perspective on working with interdisciplinary set ups and in cross disciplinary fields in order to identify and measure quantitative and/or qualitative aspects (Bryman 2006).

Social science and anthropology explore social and behavioral environments through methods that build on empirical and bodily experiences and observations. The purpose is to identify and explore acknowledged and unacknowledged needs and desires. Methods include for instance observation, interviews and cultural probes. The recently conducted research project Minimum Configuration Home Automation (MCHA) about user driven innovation for developing minimum configuration products for home automation, partly rely on methods from anthropological science (MCHA 2009). Observation, semi-structured interviews and scenario studies have uncovered behavioral patterns in the occupants' everyday habits that proved to have great impact on environmental considerations. The research showed that non-verbalized and inherent habits carry a great responsibility for the 'hidden' energy consumption (Entwistle 2010). The habits were central to uncover to implement that knowledge into developing new projects based on the needs of the occupants.

Qualitative and quantitative research methods are also used in another recently conducted Danish research project regarding the *Comfort Houses* in Vejle, Denmark (Brunsgaard 2011). Ten passive houses and their occupants are subjects to measurements. Semi-structured Interviews (Kvale 2009) was used to systematically uncover the occupants' everyday lives and experience in the low-energy house. Simultaneously interviewing the occupants, measurements on energy consumption and indoor climate conditions was conducted. The project shows that occupant behavior in a low-energy house carry a considerable impact on energy consumption. (Brunsgaard 2010)

## 2.1 Active House vision

The sustainable homes that compile the experimental setup for the project are developed from the Active House vision – a vision of:

(...) buildings that create healthier and more comfortable lives for their occupants without negative impact on the climate – moving us towards a cleaner, healthier and safer world. (Sloth 2010)

The vision defines three central categories: Energy, Indoor climate and Environment. Energy - Contributes positively to the energy balance of the building. An Active House is energy efficient and all energy needed is supplied by renewable energy sources integrated in the building or from the nearby collective energy system and electricity grid. Indoor climate - Creates a healthier and more comfortable life for the occupants. An Active House creates healthier and more comfortable indoor conditions for the occupants and the building ensures a generous supply of daylight and fresh air. Materials used have a positive impact on comfort and indoor climate. Environment - Has a positive impact on the

environment. An Active House interacts positively with the environment by means of an optimized relationship with the local context, focused use of resources, and on its overall environmental impact throughout its life cycle.

An integrated intelligent controlling system constantly monitors and adjusts the indoor climate in accordance with occupants' needs and pre-set comfort demands. The Active House vision attempts to achieve balance between the environment, house and occupants (Sloth 2010).

## **2.2 Active House Specifications**

The work of establishing the Active House vision has lead to a work-in-progress Active House Specification. The purpose of formulating a specification is to make the vision approachable and designing-tools available. This supports moving further towards the vision. (Eriksen et al 2011)

The specification state a number of parameters belonging to quantitative and qualitative fields. In keeping with the vision it is structured by the three categories Energy, Indoor climate and Environment, also stating that:

An Active House is evaluated on the basis of the interaction between energy consumption, indoor climate conditions and impact on the environment.

The parameters are listed in Table 1 under each of the categories and will form the basis of what to measure.

### **Energy**

The category implies the groupings Energy Design, Natural Design Solutions and Renewable Energy. There seem to be a gap in elaboration of the quantitative and qualitative categories as the latter is hardly elaborated on. Only design and comfort are stated as parameters in the qualitative category and

readings into the further definitions refer to the indoor climate category. Is it possible to state more elaborated qualitative parameters within energy? An approach to identifying qualitative aspects could be to relate to the values, occupants ascribe to energy; consciousness of using energy, contributing to reduction of global warming, awareness of consumption, and attitude towards producing energy.

### **Indoor climate**

The category implies the groupings Light, Thermal environment, Indoor air quality and Acoustics. This category appears to be the furthest elaborated with very specific groups and units. The category is quite approachable regarding both quantitative and qualitative aspects as the problems rely on a bodily encounter – one of physical nature and one of experiential nature. It might be problematic that the very specific parameters could call for very specific measurement methods.

### **Environment**

The category implies the groupings Resources and emission and Characteristics and culture. The parameters elaborated from only one perspective each making it difficult to see through the holistic approach to the category. The real-life-scaled project carries good odds of resulting in knowledge that can further elaborate the categories due to the contextual preconditions and its geographic extend.

The differences in degree of description and elaboration of the parameters clearly signal the work-in-progress stage of the work. However, the stated parameters will form the basis for what to measure in this initial part of the process of measuring with implied development.

## **2.3. Experimental setup**

To investigate if the proposed measurement parameters are legitimate and to explore errors or absence of aspects we will measure these

parameters in a full scale experiment of seven sustainable homes. The seven experimental houses are designed and constructed according to the Active House vision as single-family-houses of which one is a renovation project and the remaining are newly built. The houses are geographically located across Europe, with two houses in respectively Germany and Austria, while one house is built in respectively Denmark, France and Britain. This geographic extent provides an interesting basis for studies on energy optimization and importance of place and location to the experience of each house, as well as to the strengths, weaknesses and comparability of houses. Each house has distinctive characters, as they are built, taking into account local, cultural and climatic conditions and with different teams of architects, engineers and contractors. The overall perspective focuses on combining an aesthetic energy-design, high comfort and good indoor climate - while resulting in minimal environmental impacts (Hansen 2010).

When the houses are built and adjusted, families move in for a one year period to test and experience living in and with the houses. First three houses will be tested to the measurement parameters and outcomes will be analyzed. The analysis will be evaluated to analyze whether the parameters provide us with a holistic illustration of the homes and to analyze what can be enhanced regarding parameters, approach and methods. Subsequent, measurements of the remaining four homes will test and revise the model to verify it. Each house will be treated as a case study in an embedded multiple-case design (Yin 2009).

The objective is to test if the measurement parameters can help provide the required answers to the questions and help verify the stated hypotheses.

**Table 1:** What Parameters Matrix: The categories *Energy*, *Indoor climate* and *Environment* in respectively the quantitative and qualitative approach. Source: (Authors' production based on the *Active House Specification* (Eriksen et al 2011))

	Energy	Indoor Climate	Environment (surroundings)
Q U A N T I T A T I V E	<p><i>Energy design/Type of energy:</i> Space heating Water heating Ventilation Cooling and air conditioning Electricity for tech. installations Electricity for lightning Electricity for appliances</p> <p><i>Natural design solutions:</i> Passive solar energy Daylight utilisation Natural ventilation Shading during cooling season Integrated solutions User behaviour</p> <p><i>Renewable energy:</i> Energy demand Energy supply Source of renewable energy</p>	<p><i>Light :</i> Daylight Direct sunlight availability Surface reflectance</p> <p><i>Thermal environment:</i> Maximum operative temperature Minimum operative temperature Adjustability (individual control)</p> <p><i>Indoor air quality:</i> Air change Minimum air change</p> <p><i>Acoustics:</i> Limit value for inside system noise</p>	<p><i>Resources and emission:</i> Re-use of materials Minimized use of virgin non-renewable materials Minimized use of non-renewable fuel resources Minimize life-cycle emissions of greenhouse gasses</p> <p><i>Characteristics and culture:</i> To be defined in future process</p>
Q U A L I T A T I V E	<p><i>Energy design:</i> Design Comfort</p> <p><i>Natural design solutions:</i> Design Comfort</p> <p><i>Renewable energy:</i> Design</p>	<p><i>Light :</i> View out Visual privacy Visual comfort Individual control Dark bedrooms at night</p> <p><i>Thermal environment:</i> An intuitive human interface Draught Natural ventilation paths</p> <p><i>Indoor air quality:</i> Individual control Low-emitting building materials</p> <p><i>Acoustics:</i> Acoustic privacy and quietness</p>	<p><i>Resources and emission:</i> To be defined in future process</p> <p><i>Characteristics and culture:</i> Regional building typology Regional functional tradition Potentials and constraints in local climate Regional materials Harmoniously fit in landscape Impact on street- and landscapes EIA Preservation of existing values Ecological quality of the site Risks by climate changes</p>



*Home for Life, 2009, Lystrup, Denmark*

*New single-family house, 190m<sup>2</sup>*

*Picture: Adam Mørk*



*Solar Aktivhaus, 2009, Kraig, Austria*

*New single-family house, 150m<sup>2</sup>*

*Picture: Gitte Gylling*



*Haus der Zukunft, 2009, Regensburg, Germany*

*New single-family house, 175 m<sup>2</sup>*

*Picture: Gitte Gylling*



*Licht Aktivhaus, 2010, Hamburg, Austria*

*Renovated double house*

*Picture: VELUX*



*Sunlighthouse, 2010, Pressbaum, Austria*

*New single-family house*

*Picture: Adam Mørk*



*Carbon Lighthomes, Rothwell, United Kingdom, New double house*

*Picture: VELUX*



*Maison Air et Lumière, Varrières-le-Buisson, France, New single-family house*

*Picture: VELUX*

Figure 1: Seven experimental houses designed and built according to the Active House vision. Source: Authors design.



### 3. How to measure sustainable homes?

To be able to measure the identified parameters in the seven experimental, sustainable homes an identification of *how to measure* these is required. Studies of state-of-the-art research projects' use of methods from natural sciences and artistic and social sciences will inspire and support choice and compilation of methods.

How do we measure a house by its ability to improve life to its occupants? As the sustainable homes are designed from a holistic perspective measuring will similarly be approached from a cross scientific and Mixed Methods perspective, by introducing both methods from natural sciences and artistic and humanistic disciplines. Qualitative and quantitative research is often presented as two fundamentally different paradigms through which we study the social world. Through a Mixed Methods Research strategy quantitative and qualitative data are brought together to provide for comprehensive collection and analysis corresponding to holistic hybrid view on sustainability and measuring (Bryman 2006).

*"Mixed Methods Research (...) an approach to professional research that combines the collection and analysis of quantitative and qualitative data."*  
(Creswell 2009)

The Mixed Methods strategy is carried out as sequential practices where research into quantitative data is followed by research applying qualitative methods to the data. The approach can also be performed vice versa and as an iterative method. For instance measurements on quantitative data can reveal fluctuation, and to explain or explore this, qualitative methods such as interviews or observations can identify details or tendencies in e.g. user behavior (Creswell 2009).

Both quantitative and qualitative data are considered to represent aspects of the relations between occupant, house and environment, which will also be reflected in the choice of methods to study these.

#### 3.1. Measuring quantitative data

The intelligent controlling system implemented in the design of the homes is appropriate to use for logging data. The system monitors weather and indoor climate to adjust the house to the occupants' needs. Meters are placed on the system that can log and extract data on energy consumption and production, related to respectively heating and electricity, on weather and physical and behavioral indoor climate. Manual measurements on daylight can support investigations on the indoor climate light parameters, which are the most widely elaborated in the specification and daylight appear as a focal aspect in the *Active House vision* (Hansen 2010)(Osterhaus 2010)(Førland-Larsen 2009).

#### 3.2. Measuring qualitative data

Studies of the MCHA and Comfort Houses projects show that several qualitative methods can be used for studying the relations between environment, home and occupant, as e.g. observation studies, interviews or scenario-observation studies. This leads to wondering, if a triangulation of methods can support a more holistic perspective on measuring qualitative aspects?

In the studied research projects that treat experiences related to sustainable living, there seem to appear three perspectives to filtering these experiences; a private, an inter-relational and a professional (Søndergaard and Entwistle 2009) (Brunsgaard et al 2011). Inspired by this three-way perspective and a triangulation of methods a three-parted structure is suggested to build the qualitative research setup on.

*Occupants' experiences*

How can we measure occupants' experience of living in the house when we are not present? Differences between the occupants' acknowledged and unacknowledged needs and experiences of living in and with the houses are a central offset for measuring qualitative aspects. The occupants' experiences imply perspective on living in the house, why this method attempts to document experiences through the occupant's perspective. User based exploration focus on how the occupant experience life in a sustainable home and interrelations and inter-influences between occupant, house and environment have an effect on perceptions and feelings with regards to living in an intelligent and sustainable house. Registration of user experiences is based on *Cultural Probe* method. This imply that the occupant is set the task of registering data from experiences of living in the house through photos (digital camera), a log book for noting immediate thoughts (physical note book), and a diary (electronic template) (Bryman 2008) (Hastrup 2010).

#### *Interviews*

Interview is a frequently used method to gather data. The method appears in several research projects as the user perspective is gaining importance (Brunsgaard 2011) (Entwistle 2010). A qualitative interview can be based on several approaches. Inspired from the MCHA and Comfort Houses projects the *Semi-structured Life-world Interview* will be used; a method appropriate for extracting knowledge from and understanding the life-world of the interviewee (Kvale 2009). The flow of a *Semi-structured Interview* creates possibilities of sudden new questions to explore appeared subjects of interest or to navigate away from such if these are off key. New insight and knowledge might appear from unexpected sides that might come to be relevant to the research. The face to face interviews will be done in the sustainable home, establishing a safe setting. An

appropriately tailored interview-guide forms the overall framework for the interview situation consisting of questions and sub questions relating to different themes (Kvale 2009). The method help create knowledge about the experiences the occupant is able to verbalize. Also, the conversation about the occupant's everyday experiences of living in the house might result in new recognitions to the occupant. (Kvale 2009)

#### *Self experience studies*

The experience studies based on architectural theory and phenomenology are central when dealing with the hybrids between bodily and special experience. The MCHA and Comfort Houses projects does not deeply deal with this approach though considering the research approaches from more divisible perspectives. Professional knowledge about architecture is considered central to connect the different methods. First-hand empirical field study experiences can provide for an enhanced possibility of connecting the dots between occupants' behavior and statements related to the technical functioning of the house. The experience registrations are based on architectural methods, phenomenology and sensing approach, inspired by Juhani Pallasmaa (2005, 2007), Steen Eiler-Rasmussen (1989), Louis Kahn (Lobell 2008), Dean Hawkes (2008) and Peter Zumthor (2006). Registrations will be compiled in descriptive and narrative texts supported by photos.

## 4. RESULTS

Below, the results of studies in *how to measure* are presented in a matrix. The methods are presented in relation to the categories to undergo research with the intent that the proposed methods can support finding answers to the measurement parameters. This concluding matrix should be understood as framing the proposed methods in relation to

investigating the identified measurement parameters. This matrix further relates to measuring the first round of sustainable homes and thereby reflects its initial stage.

Quantitative measurements are listed as reasonably specific and are expectedly plain sailing. Qualitative measurement parameters and methods appear more indistinct and blended and expectedly it will be challenging to relate to a specific category due to an experience that experience is complex to classify.

## 5. DISCUSSION

### 5.1. On the issue of measuring

When looking into the concept of measuring in relation to buildings and architecture a lot seems to rely on quantitative means. Are the qualitative aspects of a building not considered as important to prove as the quantitative ones? Or is it simply not possible to put a formula to quality?

Qualitative aspects can immediately appear quite intangible since they rely on feelings and experiences rather than numbers. The line of thought appoints to the tangible difference inherited in respectively the quantitative and the qualitative aspects of sustainable architecture and thereby it appoints to the still stubborn persistently existing barrier between engineering and architecture disciplines.

*"I only wish that the first really worthwhile discovery of science would be that it recognized that the unmeasurable is what they're really fighting to understand, and that the measurable is only the servant of the unmeasurable; that everything that man makes must be fundamentally unmeasurable."*  
– Louis Kahn

In the above quotation by Louis Kahn from *Between Silence and the Light*, Kahn seem to

capture the essence of the tangibility of the quantitative and the qualitative. Opposed to the conventional upbringing within sustainable architecture he points to the unmeasurable – and thereby the qualitative – as the fundamental aspect. Is Kahn right in his statement? Would the quantitative aspects lose their justification without their dependence on qualitative aspects? Hopefully, the studies in the experimental sustainable homes can bring us closer to answering these wonderings.

### 5.2. On what to measure

The listed measurement parameters seem quite un-done – are they elaborated enough within the three categories to result in a holistic illustration and rightful fulfillment of the ambitious *Active House vision*?

Is it possible to state more elaborated qualitative parameters within *energy* and why does the descriptions of the parameters refer to the indoor climate category? Are there no qualities in energy?

The initial test-period of the experimental houses is presumed to indicate if, how and which proposed methods can answer to the stated measurement parameters – and which will prove unsuitable. This will influence the further process revision of whether the measurement parameters are accurate enough to answer to some of the aspects of the *Active House vision*.

The three measurement categories Energy, Indoor Climate and Environment and their listed parameters obviously have their restrictions at this stage of the *work-in-progress*. It would justify all of the categories to be further explored and elaborated in this attempt to establish a specification. This project will hopefully yield to defining the singular categories and parameters.

**Table 2: What Methods Matrix (first draft):** Matrix of *what* quantitative and qualitative *methods* to use for data collection related to each of the categories Energy, Indoor climate and Environment.

Source: (Authors production based on a compilation of the *Active House Specification* (Eriksen et al 2011))

	Energy	Indoor Climate	Environment (surroundings)
Q U A N T I T A T I V E	<p>Meters are placed on energy consuming and producing devices. Data are logged as mean hourly values.</p> <p><i>Logging:</i> Heating consumption: Space heating (kWh/m<sup>2</sup>/mth) Water heating (kWh/m<sup>2</sup>/mth) Electricity consumption: Ventilation (kWh/m<sup>2</sup>/mth) Cooling/air con. (kWh/m<sup>2</sup>/mth) Electricity for technical installations, lightning, appliances (kWh/m<sup>2</sup>/mth)</p> <p><i>Natural design solutions:</i> Passive solar energy: Indirect evaluation as by energy savings Daylight utilisation: Lux + electricity Natural ventilation: Indirect eval. Shading during cooling season on integrated solutions measured by logging data in awning position. User behaviour measured through collection of super steering of system and presence data</p> <p><i>Renewable energy:</i> Heating production (kWh/m<sup>2</sup>/mth) Electricity production (kWh/m<sup>2</sup>/mth)</p>	<p>House is separated into zones (rooms/areas) constantly measured. Meters placed on walls 1.6 m above floor in shadow. Data are logged as mean hourly values</p> <p><i>Light :</i> Lux data are logged (lx) Time Lapse Luminance mapping/pictures ()</p> <p><i>Thermal environment :</i> Temperature data are logged (°C)</p> <p><i>Indoor air quality:</i> CO<sub>2</sub> data are logged as mean hourly values (ppm) Relative Humidity data are logged as mean hourly values (%)</p> <p><i>Acoustics:</i> Observation of the acoustic environment will help determine whether measurements of the acoustic environment in and around the house are required</p>	<p>Logging weather data – meters are placed on roof top constantly measuring. Data are logged as mean hourly values.</p> <p><i>Weather:</i> Outdoor temperature (°C) Outdoor lux (lx) Rain (1/0) Wind speed (m/s)</p> <p><i>Resources and emission:</i> Registration Evaluation through comparison to calculation</p> <p><i>Characteristics and culture:</i> Indirect evaluation through quantitative measurements and description.</p>
Q U A L I T A T I V E	<p><i>Energy design:</i> Occupant experiences/Cultural Probes Semi-structured Interviews Self-experience studies <i>Natural design solutions:</i> Occupant experiences/Cultural Probes Semi-structured Interviews Self-experience studies <i>Renewable energy:</i> Occupant experience/Cultural Probe Semi-structured Interviews Self-experience studies</p>	<p><i>Light :</i> Occupant experiences/Cultural Probes Semi-structured Interviews Self-experience studies Time Lapse studies Luminance photos/mapping Light narratives <i>Thermal environment, Indoor air quality and Acoustics:</i> Occupant experiences/Cultural Probes Semi-structured Interviews Self-experience studies</p>	<p><i>Resources and emission:</i> Occupant experiences/Cultural Probes Semi-structured Interviews Self-experience studies <i>Characteristics and culture:</i> Registered through photo registration Description Occupant experiences/Cultural Probes Semi-structured Interviews Self-experience studies</p>

Measuring the sustainable homes will hopefully result in answers to some of the questions, providing for specification of the parameters within the three categories.

### **5.3. Challenges to the experimental setup**

There are big challenges in this measuring setup. The experimental houses are designed and constructed by different companies, with different teams of architects, engineers, entrepreneurs and project managers, in different countries, with different climate and different legal regulation and standards. The house designs are different, building traditions and materials are different, the habit of living is different, the people are different. These cultural aspects must stand in the background for the central aspects regarding environment – the ability to adaption to climate and surroundings and the occupants' experiences of living in and with the sustainable houses. These aspects can help identify how we can make comparison across. This makes it possible to demonstrate differences and coincidences in occupants' wishes and requirements to a sustainable home in accordance with place.

### **5.4. On how to measure**

The proposed methods matrix suggests a lot of different methods through the Mixed Methods research strategy, but can the generous use of methods and scientific directions course for confusion rather than clarity in the explorations? Could the intent to research the different aspects of sustainable homes by triangulation course for blurred results or contrary results? It might. In that case, it is central to keep focus on the holistic purpose of the explorations. We are not searching for single rights or wrongs but rather for inspiring and interesting tendencies to support our hypothesis in qualified ways. Here, the professionalism and discernment of the

researcher must be considered the right tool for determining the answers.

The study proposes methods to intercept qualitative aspects and set off to explore whether these methods are any good for the job?

### **5.5. On results**

In order to extract knowledge to implement in the further process the measurements must be analyzed properly and according to the idea of focusing on a holistic approach and the interplay between quantitative and qualitative aspects. What are more important – quantitative or qualitative aspects of the houses? If it is possible to make such a distinction is very relevant to the discussion of the need for a holistic approach.

### **5.6. On analyses**

How do we treat and analyze data and information in order to be able to answer to the questions? The various methods and approaches calls for various analysis approaches. The data will be gathered in NVivo (qualitative data analysis software (Lewins and Silver 2007)) and analyzed through an inductive approach to explore options in the data. Deductive and inductive analysis approaches will both be relevant to detect the worth of the data (Watt Boolsen 2006).

The case study research (Yin 2009) approach to the setup for exploration enable for comparable studies in the analysis phases of the project. By using the same methods for data collection comparability studies will have similar premises and studies can be possible across e.g. different themes or typologies. The setup enables numerous permutations providing for uncovering both expected and unexpected areas of the explorations. Further strategies for

data analysis will be uncovered in the succeeding stages of the project.

### 5.7. Validity, reliability and generalizability

This research project focus on sustainable homes spread across five European countries. The results of the three initial case studies in respectively Denmark, Austria and Germany will indicate whether this geographic extend hold any kind of generalizability.

It is our belief, that a vision of successful development of sustainable homes, as of sustainable architecture in general, requires a more holistic approach regarding all phases of building, from design phase to operation phase. Focus on holistic, inter-disciplinary design processes would make the preconditions for successful holistic assessment greater.

This initial proposal for systematically exploring sustainable homes cannot be considered a final answer to the issues, but rather an attempt to prove the validity of the hypotheses. Hopefully, this way of systemized method for gathering data will prove its worth. Very different methods and approaches are introduced for exploring different areas of the problem and discovering whether these support or undermine each other will be a key to deciding for the further development for the collection matrix.

## 6. CONCLUSION

The paper studies the *Active House vision* and the *Active House Specification work-in-progress* to identify what parameters to measure related to both quantitative and qualitative aspects in relation to the categories Energy, Indoor climate and Environment. On basis of the measurement parameters a set of methods are compiled into a matrix that defines what to measure regarding quantitative and qualitative aspects.

The conclusion is must evaluate the buildings on their preconditions – their design parameters and visions for the individual building to identify whether the design parameters are good enough. In order to answer to our questions we must analyze a combination of quantitative and qualitative data.

## 7. ACKNOWLEDGEMENTS

This paper is the second paper in the PhD project *A Method for Holistic Evaluation of Sustainable Buildings of the Future* where quantitative and qualitative measurements of seven buildings in five European countries - built according to the Active House vision - will contour the setup for development of a method for holistic evaluation of sustainable homes.

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***Holistic Evaluation of Sustainable Buildings through  
a Symbiosis of Quantitative and Qualitative Assessment Methods***

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<http://www.plea2011.be/BestPaper.html>

# Holistic Evaluation of Sustainable Buildings through a Symbiosis of Quantitative and Qualitative Assessment Methods

*ABSTRACT: Through the last decades there has been a growing interest in quantitative assessment of building performance in line with the technical and practical development of sustainable buildings. Now, contours of a more holistic approach to sustainable buildings begin to emerge, for instance in the Active House vision, and the technological and practical development follow suit. The holistic approach calls for new ways to assess and evaluate our buildings, not solely based on quantitative means but particularly also based on qualitative means, so we can determine qualities and life improving factors in order to develop sustainable, energy-producing, CO<sub>2</sub>-neutral buildings, with good and healthy indoor climate, designed with regard to the surrounding environment. In this paper we will review existing quantitative evaluation methods and study state-of-the-art in qualitative evaluation methods. We will discuss potential in a holistic evaluation method as a symbiosis of quantitative and qualitative assessment with the objective to evaluate sustainable buildings.*

*Keywords: Quantitative assessment methods, qualitative assessment methods, sustainable buildings, Active House, occupants, holistic evaluation method*

## INTRODUCTION

Development of sustainable architecture has intensified during the past forty years and now we are sketching our visions of the future. We see potential in buildings developing into being energy producing rather than consuming, leading our minds to imagine a future, where we give more than we take. Increasing desire to live better and longer, be healthier and more full-filled as human beings and re-establish our relationship with nature and quality are becoming important aspects in our lives.

The holistic approach calls for new ways to assess and evaluate our buildings, not solely based on quantitative means but particularly also based on qualitative means, so we can determine qualities and life improving factors in sustainable architecture.

In this paper we claim it is central to develop a more holistic evaluation method for sustainable buildings of the future to ensure that experiential devices are considered as important as technical aspects when we develop sustainable, energy-producing, CO<sub>2</sub>-neutral buildings, with good and healthy indoor climate, designed with regard to the surrounding environment and the user in centre. By synthesizing quantitative and qualitative evaluation aspects we can answer to the increasingly holistic development of sustainable architecture; and intent that future buildings are not merely optimized mechanical buildings with intelligent adjustment systems but constructions that imply and require quality in their environments to support and embrace life displayed in and around them. We believe that by pushing for implementation of qualitative aspects in evaluation, we can influence the quality of development of sustainable architecture, and advocate our opinion, that within sustainable

buildings of the future the aspects we experience are as important as the aspects we measure.

The paper consists of four sections considering areas we find important to support our claims:

Sustainable architecture: Architecture and legislation from 1970 till now and future tendencies.

Quantitative evaluation: A review of traditional and more recent developments in Building Environmental Assessment (BEA) methods and their focuses.

Qualitative evaluation: A reflection upon quality in architecture and experimental projects

Potential in holistic evaluation: A discussion of potential in a more holistic approach for evaluation of sustainable buildings of the future.

### Sustainable architecture

The 1970ies energy crisis incited architects to develop buildings from a new and sustainable perspective, and since then the understanding of sustainability has changed as has the interpretation of sustainable buildings [1]. The technical pioneers of the 1970s consider green buildings as energy saving devices and focus on developing building technologies to improve energy performance. The 1980s induced alternative ways of building and of thinking about sustainability with strong self-builder ideologies. During the 1990s sustainability turns from ecology to hi-tech projects in larger scale where display of renewable energy technologies such as solar cells becomes an important measure in displaying sustainability. The 2000s present a normalization bringing sustainability from prestige buildings to homes scale. [1] [2]

Now, we see the contours of the 2010s describing holistic solutions with input from all of the previous paths to benefit from existing knowledge and also tendencies of considering the human as the focal point when developing and constructing sustainable buildings. [3]

New initiatives are taking shape as e.g. the Active House vision, a strategic concept aiming for a common European influence, developed in European context by the Active House Alliance. Active House is a vision of buildings that create healthier and more comfortable lives for their occupants without impacting negatively on the environment. *“The Active House vision defines highly ambitious long term goals for the future building stock.”* [3] The Active House vision defines sustainable buildings as a building that has a positive impact on the environment, contributes positively to the energy balance by producing more energy than it consumes, and creates healthier and more comfortable lives for its occupants. The vision deals with a three branched structure consisting of Energy, Indoor Climate and Environment with the objective to establish a holistic model of the future. [3]

#### SUSTAINABLE ARCHITECTURE

1970	Technical pioneers consider green buildings as energysaving devices; focus on developing building technologies to improve energy performance.
1980	Alternative ways of building and thinking about sustainability with strong selfbuilder ideologies: new concepts such as the Passivhaus standard appeared.
1990	Turn from ecology to hi-tech projects in large scale; display of renewable energy technologies e.g. solar cells becomes important to signal sustainability.
2000	Normalization of sustainable architecture bring sustainability from prestige buildings to home scale; ecology and recycling gain focus.
2010	Contours of holistic solutions emerge: occupants

Figure 1: Development and tendencies in sustainable architecture from 1970ies to present.

## Legislation and regulation

When addressing sustainable architecture the area of legislation and regulation is central, due to its effect on possibilities in development.

In the 1987 proceedings in Norway entitled *Our Common Future* the Brundtland Commission stated a global agenda for change by outlining strategic improvements on environmental issues: *“Sustainable development seeks to meet the needs and aspirations of the present without compromising the ability to meet those of the future”* [4]. This statement describes a visionary approach displaying great will, but also inaccuracy since the concept is open to various readings, and has resulted in various sub definitions [5]. Overall the definitions have the three common themes: environmental, economic and social sustainability [6] [2].

Evidence for global warming emerged in the 1980ies and focus on a common effort for reduction of greenhouse gasses (GHG) became verbalized through the 1992 United Nation’s Rio Earth Summit [5] ultimately leading to climate legislation. The 1997 Kyoto Agreement commits its members to reduce GHG emissions [7].

The draft for the European legislative contribution appears in 2002 the “Energy Performance of Buildings Directive” (EPBD) [8]. The Directive states the common legislative targets which are subsequently implemented in member countries national strategies and legislation. The EPBD requires that all new buildings in Europe by 2020 are *nearly zero energy buildings* and that all member countries at once must set targets for 2015 [8]. Legislation is implemented in the EU member countries by establishing codes and classes adjusted to national standards, to make the legislative initiatives operational.

## Quantitative Assessment

The term Building Environmental Assessment (BEA) covers a group of methods or tools for comprehensive assessment of environmental performance of buildings. BEA is based on Life Cycle Assessment (LCA) methodology originally developed on basis of interests in environmental assessment in the United States in the 1960s [5]. In the late 1990s the increasing focus on LCA lead to the establishment of a worldwide environmental management tool in the form of the ISO (International Organization for Standardization) 14040 series [9].

BEA's are developed in various versions with different fields of focus, but the overall principles are analogous. Generally, the existing BEAs set the scene for integrating sustainable aspects already during the early programming stages of the process, but they are currently being used in different stages of the design process. The design of BEAs consists of a set of prime themes: environmental sustainability, social sustainability and economic sustainability. BEAs lead to a type of certification or labeling of the assessed object by weighing and rewarding the themes according to different structures. The label is a way of categorizing the buildings in relation to how good it performs when weighed up against the specific system (e.g. [6] or [1]). Most common structures are based on point or percentages used for awarding the various themes.

Often the themes are not awarded points in an equally distributed structure, but are differentiated in accordance with focus of the BEA. This goes for BEA methods as BREEAM (UK), LEED (US) and DGNB (G) while an exception to the rule is HQE (F) which has a completely flat structure [6] [10] [11] [12] [13].

A problematic issue with the structures is that a building does not necessarily have to score highly on all levels in order to obtain a high classification, which might unintended undermine certain themes. This can be problematic in order to maintain a holistic focus. Though there are quantitative and qualitative issues of the assessment methods, all systems seem to be based on quantitative systematic, where all issues and themes are reduced or equalized to numbering percentage systems [5].

The original focus in BEAs stem from quantitative issues related to the environment. Quantitative issues as energy and water consumption, waste and pollution, water savings, materials selection and indoor environment are highly rewarded in the point systems of methods like BREEAM, LEED and DGNB. Many BEAs integrates qualitative aspects such as experienced indoor air quality, healthy spaces, well-being, health and comfort, a method as HQE (France) especially rate these themes highly.

With the entry of the new more holistically designed buildings, we need more holistic assessment methods. Initiatives supported by EU such as LEnSE, SuPerBuildings, OPEN HOUSE and iiSBE are currently developing and are all examples of state of the art work that support establishment of common sustainable building assessment methodology with more holistic focus, to complement existing ones on international, European or national level. [14] [15] [16] [17]

*Figure 2: Weighing systems of different BEA methods.*

## Qualitative Assessment

The section will attempt to identify how we can qualitatively evaluate buildings by studying architectural tradition, architects' evaluation strategies based on architectural professionalism and Evidence-based design (EBD).

Architectural traditions have developed through centuries with strong inherent understanding for qualities based on cultural, scenic, spatial and social realms through an art of refining combination of materials, space, light, function and landscape. In *Ten Books on Architecture* the roman writer, architect and engineer (70bc–15ac) Vitruvius describes architecture as unity of Venustas, Utilitas and Firmitas (Beauty, Usability and Durability) a model supporting that it is the symbiosis of the concepts that creates the architecture and not the separate elements [18].

Architects are challenged and committed to visualize qualities in our surrounding environments, whether it is parks, buildings or intimate spaces. There are subjective opinions about what constitutes quality within architecture or the art of buildings, and they all depend on the eyes that see. In architecture there is not a simple quantitative answer to a building design and contrary to natural sciences this is not the objective. Architecture proposes individual interpretation with the subject as a vital parameter and architecture is created in the encounter between human being and building structure.

When studying qualities in architecture a specific qualitative assessment methodology does not seem to exist in the same understanding as quantitative ones do. The discipline of qualitative assessment of architecture appears to be an inherent discipline living within the art of creating and evaluating architecture. But what is

quality in architecture? And how do we define and depict this quality?

Through decades architects and philosophers have asked themselves, with the shared aim to be able to create quality, trying to depict the themes and poetic devices important in their own work.

Danish architect and writer Steen Eiler Rasmussen writes about themes as *Seeing and experiencing solids and space*, *Textual effects* and *Daylight in architecture* in his book "Experiencing Architecture" [19]. He explains experiences and phenomena that establish a sense of quality in architecture to him.

In his lecture *Atmospheres* (transformed into a small book) [20] architect Peter Zumthor describes his idea of *the Magic of the Real*, a concept analogous to quality in architecture. Zumthor questions how *the Real* can be grasped in architecture, and answers by applying the concept *Atmosphere* which he divides into nine categories: *The Body of Architecture*, *Material Compatibility*, *The Sound of Space*, *The Temperature of a Space*, *Surrounding Objects*, *Between Composure and Seduction*, *Tension between Interior and Exterior*, *Levels of Intimacy* and *The Light on Things*. About *The Light on Things*, Zumthor says: "I spent five minutes or so looking at the actual appearance of things in my living room. What the light was like. And it was great! I'm sure you've had the same experience. Where and how the light fell. Where the shadows were. And the way the surfaces were dull or sparkled or had their own depth." [20].

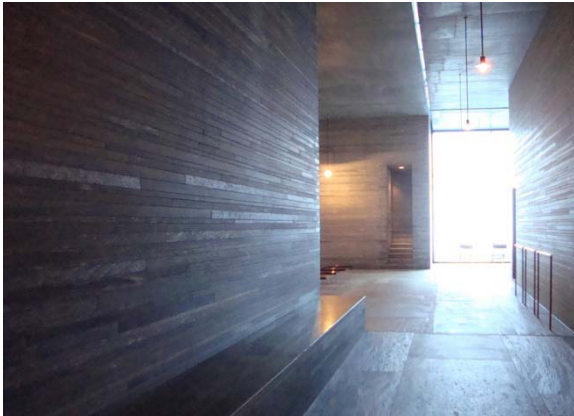


Figure 3: Peter Zumthors Thermenhof Vals in Switzerland; light and shadow play with rough stone. Picture by Gitte Gylling.

Finish architect and philosopher Juhani Pallasmaa represents a phenomenological approach to architecture by seeking experiences by phenomena in encounters between architecture and the senses. Pallasmaa writes: *“The design of a building and its interior space influences its atmosphere and lends a specific character. Together with the features of the room itself the lighting, the materials used, their surfaces, textures and colourings help creating the effect of space”* [21].

Evidence-based design (EBD) is a field of study, which accentuate importance of using evidence data in design processes [22]. EBD has especially gained footing within the field of Healthcare Architecture, with the aim to improve well-being and healing process. Thereby the evidence of quality in architecture can be determined by the buildings ability to improve the life of its users. Studies show that plenty of daylight and fresh air as well as relations to the surrounding environment by e.g. views are life improving parameters. Through EBD we can deal with issues of architecture that verify that qualitative parameters are central so that we can prove the importance of these parameters as well as we can with the quantitative ones.

Though we find no direct methodology to assessing qualities in architecture the tendencies

in EBD paired with architectural tradition and the three exemplified approaches indicates substance in assessing the qualitative at a level comparable to the quantitative. All the studied issues point to importance of the user. In the light of this below we argue that users are central to determination of qualities in sustainable buildings of the future.

## Experimental projects

Three ongoing Danish experimental projects research sustainable buildings and user behaviour where users test state-of-the-art sustainable buildings with the overall objective to identify relations regarding sustainable issues between user and building.

Experimental projects move proposed ideas and solutions from vision to reality. Experiments have proved valuable to development of knowledge on practical, technical and social levels through several projects. Engineer and inventor Villum Kann Rasmussen stated that: “One experiment is better than a thousand expert views” a philosophy that lead him to develop e.g. the VELUX skylight in 1942 [23].

Experimental project on the subject of sustainable buildings are emerging as collaborative projects between the industry and research institutions and slowly begin to establish the ground for implementing research results directly in development of e.g. product solutions (e.g. {{70 Web}}). The industry is gaining awareness that it is no longer sufficient to base development of sustainable buildings and products on technical knowledge alone, why users are becoming an increasingly important factor. The importance of developing with regard to users’ needs and desires is increasing, and industries are now pushing the development by integrating user experiences in their development.

In her PhD project 'Concepts of Passive Houses in Denmark' [24] Camilla Brunsgaard from Aalborg University study the *Comfort Houses* in Vejle, Denmark, constructed according to Passivhaus standard in collaboration between Zeta Invest, Middelfart Sparekasse, and Isover {{98 Saint-Gobain Isover 2010}}. Through interviews she follows the houses while test families live in them to study architectural language, low-energy concept, building technology, indoor climate and quality of life. *"The news in this research is to study the user's opinion and perception of architecture and quality of life in low-energy buildings and that this knowledge is integrated into solutions of structure and energy as well as guidelines for concepts of passive house in a Danish context which has a future commercial potential."* [24]

The research project *Monitoring Interviews Measuring and Analysis* (MIMA) is a knowledge and research project anchored in the Active House vision from which eight houses in five European countries are designed and constructed in collaboration with industrial firms VELFAC, VELUX, SONNENKRAFT and WindowMaster. One MIMA project study energy, indoor climate and environment in relation to occupants' experiences in *Home for Life*, while a test family live in the house for one year, by measuring energy consumption and production that results from the user behaviour and analogously interviewing and observing the family with regards to their opinion and experiences of living in an energy producing house. [24]



Figure 4: *Home for Life* and its users are tested in the MIMA project to identify needs and possibilities of future users. Picture by Gitte Gylling.

EnergyFlexHouse in Tåstrup is developed in collaboration between the Danish Technological Institute and a large number of industrial sponsors and interested parties. EnergyFlexHouse consists of two almost similar buildings constructed side by side, which functions as laboratories for development of energy sufficient solutions for homes. One house is an actual home where families move in to test the house and here focus is on testing the interplay between technology and user. The second house inhabits different equipment for testing and measuring and possibilities to switch between the different systems and building components to test the different coherences. The aim of the project is to develop energy efficient technologies that meet the global challenges within reduction of energy and CO<sub>2</sub> emissions and utilization of renewable energy [26].

All the described experimental projects focus on energy optimization combined with the occupant's perspective, providing possibilities for considering and respecting human perspectives when developing products and buildings for the future market. The tendency reflect a deductive approach closely related to actual needs and desires, and this subsequently creates possibilities for considering these aspects in an integrated design process where the occupant becomes the starting point. This supports our claim that users



are a core parameter when developing and assessing sustainable buildings of the future and also points to a more loosely defined evaluation method adjustable to individual users needs.

## Potentials in holistic evaluation

This section will discuss potentials in a holistic evaluation method as a symbiosis of quantitative and qualitative assessment by reflecting on the issues studied in present paper.

Generally, all the studied issues point towards more holistic tendencies in development of future sustainable architecture, supporting our belief of potential in developing a holistic evaluation method.

## Sustainable architecture and quality

There seems to occur a clash between the traditional architecture with its inherent qualities and the developed technically oriented sustainable tendencies. This results in sustainable technologies taking focus, due to the fact that technological aspects are designed on premises that can be demonstrated rather than the inherent experiential architectural qualities of more perceptual, sensuous and poetic art. The contrast within this conflict points to a more holistic way of designing with offset in users and user's needs. Gradually sustainable architectural tendencies have been optimized and developed on basis of utilizing nature's resources, subsequently taking to quantitative aspects in buildings e.g. indoor climate. Though there exist good examples of sustainable architecture tendencies are that these buildings often seem to lack qualities and are just buildings which can appear as machines to live in. What constitutes the holistic building is the sum of all its parts that makes all aspects interdependent, thereby quantitative and qualitative aspects are interrelated exposing and

supporting each other's strengths and weaknesses. At last, all the aspects depend on the users' understanding of the building.

## Legislation

Through the study of legislation in relation to sustainable development, we find that legislation has impacted development of quantitative assessment methods. BEAs are being developed so they can be implemented in accordance with valid conditions; otherwise they do not make much sense. Legislation is making it complicated to implement qualitative aspects in the methods, due to their complexity in relation to existing legislation. Attempts have so far resulted in quantifying the qualitative aspects in order to implement these in BEA methods on equal terms. Can find better ways to translate this complexity to make it further comparable to quantitative aspects?

Potential of influencing the tendency might occur by appointing importance of the holistic perspective through users' demands and needs, if we can prove these are central. A potential can also be to try and influence legislation to regulate for qualities in the same manner as is already the case for more quantitative aspects.

## Quantitative and qualitative assessment

In this paper we have presented both quantitative and qualitative assessment approaches since both are considered important. Despite this approach there is a risk in separating the two into different categories, because in this paper we intent to demonstrate, that they belong together in synthesis.

Baring the holistic view point in mind current certification systems such as BREEAM and DGNB

can be viewed as inadequate as quantitative aspects apparently tend to overtrump qualitative ones. This displaces the balance between architects and engineers during the entire process of developing a building, providing the engineering arguments the better hand, while architects experience the technical approach as restrictive to their possibilities.

## Evaluation method

We plan to approach the holistic method through creating a symbiosis of quantitative and qualitative aspects and wish to plot this course to attempt to capture the complexity of future buildings.

A BEA tend to rate success by the sum of its variables exceeding a certain level leading to the unfortunate dilemma, that one single variable can generate enough points and thereby making other variables insignificant to the total. Figure 5 in concept illustrates the traditional BEA method where all themes are pluralized to find the level of certification. The figure 5 show that here one of the themes alone is tall enough to obtain a level D certification.

*Figure 5: Conceptual diagram of traditional BEA method.*

Opposite normal BEAs we point towards an evaluation strategy where all issues have to reach at least a certain level, to avoid some parameters are being excluded; a system where fulfilment of

both quantitative and qualitative issues are required.

*Figure 6: Conceptual diagram of a holistic evaluation method – the dotted line define minimum requirement for quantitative and qualitative aspects.*

Current methods suggest separating quantitative and qualitative aspects when rating to be able to distinct what belongs in what categories. Contrary to this, we suggest establishing symbiosis so each subject always depends on quantitative *and* qualitative issues; one approach cannot trump the other; but the solution lie in the interrelatedness and synthesis. Each theme must fulfil both qualitative and quantitative aspects; together the pillars create a hybrid visualization of whether the building passes (see figure 6).

Systems such as LEnSE, SuPerBuildings, OPEN HOUSE and iiSBE are currently developing and sketch a more holistic course. We find these systems to be quite similar to our approach; being also cross national approaches and considering qualities higher than traditional BEAs do. However, our approach differs by considering the user – the occupant – the central point of assessment. This perspective helps bridging the gap between quantitative and qualitative aspects, because it moves focus to the needs of the user. This leads to the mentioned symbiosis effect relating to Vitruvius' holistic view of architecture [18] – themes alter from being *either* quantitative *or* qualitative to being *both* quantitative *and* qualitative.

## CONCLUSION

This paper has argued that there are true potential in development of a methodology for more holistic evaluation of sustainable buildings of the future, if we intend for technical solutions and experiential devices to go hand in hand. Development of such a method will be approached from holistic view point defining the user of the building as the centre of interest on which both quantitative and qualitative aspects depend. A symbiosis will be attempted to obtain through constantly considering *both* quantitative

*and* qualitative aspects when evaluating so that one never trumps the other.

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## PART VI | Background

## 6.1 Bibliography

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**Gitte Gylling Hammershøj Olesen** was born in Randers, Denmark, in 1983. She received the B.S. and M.S. degrees in civil engineering with specialization in architecture from Aalborg University in Denmark in 2009. From ultimo 2009 to primo 2014 she was doing her Industrial Ph.D. study in sustainable architecture at Department of Architecture & Media Technology at Aalborg University in Denmark in collaboration with skylight inventor and producer VELUX A/S and holding and investment company VKR Holding.

Profile, Aalborg University: [http://vbn.aau.dk/da/persons/gitte-gylling-hammershoej-olesen\(4276205f-c88d-407e-864c-2ae3226fd695\).html](http://vbn.aau.dk/da/persons/gitte-gylling-hammershoej-olesen(4276205f-c88d-407e-864c-2ae3226fd695).html)

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*Gitte Gylling Olesen, Mary-Ann Knudstrup, Per K. Heiselberg & Jens Christoffersen (2014)*

Submitted to *Indoor and Built Environment*.

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*Haus der Zukunft, Quantitative Performance, Month statement, June 2010, Gitte Gylling H. Olesen.*

*Haus der Zukunft, Quantitative Performance, Month statement, July 2010, Gitte Gylling H. Olesen.*

*Haus der Zukunft, Quantitative Performance, Month statement, August 2010, Gitte Gylling H. Olesen.*

*Haus der Zukunft, Quantitative Performance, Month statement, September 2010, Gitte Gylling H. Olesen.*

*Haus der Zukunft, Quantitative Performance, Month statement, October 2010, Gitte Gylling H. Olesen.*

*Haus der Zukunft, Quantitative Performance, Month statement, November 2010, Gitte Gylling H. Olesen.*

*Haus der Zukunft, Quantitative Performance, Month statement, December 2010, Gitte Gylling H. Olesen.*

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*Haus der Zukunft, Quantitative Performance, Month statement, February 2011, Gitte Gylling H. Olesen.*

*Haus der Zukunft, Quantitative Performance, Month statement, March 2011, Gitte Gylling H. Olesen.*

*Haus der Zukunft, Quantitative Performance, Month statement, April 2011, Gitte Gylling H. Olesen.*

*Haus der Zukunft, Quantitative Performance, Month statement, May 2011, Gitte Gylling H. Olesen.*

*Haus der Zukunft, Quantitative Performance, Month statement, June 2011, Gitte Gylling H. Olesen.*

*Haus der Zukunft, Quantitative Performance, Month statement, July 2011, Gitte Gylling H. Olesen.*

*Haus der Zukunft, Quantitative Performance, Month statement, August 2011, Gitte Gylling H. Olesen.*

*Haus der Zukunft, Quantitative Performance, Month statement, September 2011, Gitte Gylling H. Olesen.*

*Haus der Zukunft, Quantitative Performance, Month statement, October 2011, Gitte Gylling H. Olesen.*

*Haus der Zukunft, Quantitative Performance, Month statement, November 2011, Gitte Gylling H. Olesen.*

*Haus der Zukunft, Quantitative Performance, Month statement, December 2011, Gitte Gylling H. Olesen.*

*Haus der Zukunft, Quantitative Performance, Month statement, January 2012, Gitte Gylling H. Olesen.*

*Haus der Zukunft, Quantitative Performance, Month statement, February 2012, Gitte Gylling H. Olesen.*

**Solar Aktivhaus, Kraig, Austria, MIMA Month statement reports**

*Solar Aktivhaus, Quantitative Performance, Month statement, June 2010, Gitte Gylling H. Olesen.*

*Solar Aktivhaus, Quantitative Performance, Month statement, July 2010, Gitte Gylling H. Olesen.*

*Solar Aktivhaus, Quantitative Performance, Month statement, August 2010, Gitte Gylling H. Olesen.*

*Solar Aktivhaus, Quantitative Performance, Month statement, September 2010, Gitte Gylling H. Olesen.*

*Solar Aktivhaus, Quantitative Performance, Month statement, October 2010, Gitte Gylling H. Olesen.*

*Solar Aktivhaus, Quantitative Performance, Month statement, November 2010, Gitte Gylling H. Olesen.*

*Solar Aktivhaus, Quantitative Performance, Month statement, December 2010, Gitte Gylling H. Olesen.*

*Solar Aktivhaus, Quantitative Performance, Month statement, January 2011, Gitte Gylling H. Olesen.*

*Solar Aktivhaus, Quantitative Performance, Month statement, February 2011, Gitte Gylling H. Olesen.*

*Solar Aktivhaus, Quantitative Performance, Month statement, March 2011, Gitte Gylling H. Olesen.*

*Solar Aktivhaus, Quantitative Performance, Month statement, April 2011, Gitte Gylling H. Olesen.*

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*Solar Aktivhaus, Quantitative Performance, Month statement, September 2011, Gitte Gylling H. Olesen.*

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*Solar Aktivhaus, Quantitative Performance, Month statement, January 2012, Gitte Gylling H. Olesen.*

*Solar Aktivhaus, Quantitative Performance, Month statement, February 2012, Gitte Gylling H. Olesen.*

**Greenlighthouse, Copenhagen, Denmark, MIMA Month statement reports**

*Greenlighthouse, Quantitative Performance, Month statement, January 2011, Gitte Gylling H. Olesen.*

*Greenlighthouse, Quantitative Performance, Month statement, February 2011, Gitte Gylling H. Olesen.*

*Greenlighthouse, Quantitative Performance, Month statement, March 2011, Gitte Gylling H. Olesen.*

*Greenlighthouse, Quantitative Performance, Month statement, April 2011, Gitte Gylling H. Olesen.*

*Greenlighthouse, Quantitative Performance, Month statement, May 2011, Gitte Gylling H. Olesen.*

*Greenlighthouse, Quantitative Performance, Month statement, June 2011, Gitte Gylling H. Olesen.*

*Greenlighthouse, Quantitative Performance, Month statement, July 2011, Gitte Gylling H. Olesen.*

*Greenlighthouse, Quantitative Performance, Month statement, August 2011, Gitte Gylling H. Olesen.*

*Greenlighthouse, Quantitative Performance, Month statement, September 2011, Gitte Gylling H. Olesen.*

*Greenlighthouse, Quantitative Performance, Month statement, October 2011, Gitte Gylling H. Olesen.*

*Greenlighthouse, Quantitative Performance, Month statement, November 2011, Gitte Gylling H. Olesen.*

*Greenlighthouse, Quantitative Performance, Month statement, December 2011, Gitte Gylling H. Olesen.*

*Greenlighthouse, Quantitative Performance, Month statement, January 2012, Gitte Gylling H. Olesen.*

*Greenlighthouse, Quantitative Performance, Month statement, February 2012, Gitte Gylling H. Olesen.*

**Home for Life, Lystrup, Aarhus, Denmark, MIMA Month statement reports**

*Home for Life, Quantitative Performance, Month statement, November 2010, Gitte Gylling H. Olesen.*

*Home for Life, Quantitative Performance, Month statement, December 2010, Gitte Gylling H. Olesen.*

*Home for Life, Quantitative Performance, Month statement, January 2011, Gitte Gylling H. Olesen.*

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*Home for Life, Quantitative Performance, Month statement, June 2011, Gitte Gylling H. Olesen.*

*Home for Life, Quantitative Performance, Month statement, July 2011, Gitte Gylling H. Olesen.*

*Home for Life, Quantitative Performance, Month statement, August 2011, Gitte Gylling H. Olesen.*

*Home for Life, Quantitative Performance, Month statement, September 2011, Gitte Gylling H. Olesen.*

*Home for Life, Quantitative Performance, Month statement, October 2011, Gitte Gylling H. Olesen.*

*Home for Life, Quantitative Performance, Month statement, November 2011, Gitte Gylling H. Olesen.*

*Home for Life, Quantitative Performance, Month statement, December 2011, Gitte Gylling H. Olesen.*

*Home for Life, Quantitative Performance, Month statement, January 2012, Gitte Gylling H. Olesen.*



# 6.2 Appendix

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The appendix contains data collection templates designed and developed through the research enquiry.

## Data collection templates

- Technical measurement
- Questionnaire scheme
- Blog references
- In-situ scheme



## Technical measurements

### Measurement application

Measurements are carried out as long term measurements using sensors installed in all spaces in the house in a specifically selected position in each of the rooms. As occupants live in the house during the test year measurements are performed on occupied spaces. Enquiries explore the house in general (calculated as average value of all sensors except sensor in technique room since this is not a place for staying) and three selected rooms: Kitchen, Living room and Bedroom. The rooms are selected based on that these are spaces commonly used by the entire family or the grownups in particular.

### Types of data

Types of data measured are stated in **ill. 5.2.2. Data logging overview** while **ill. 5.2.1. What Parameters Matrix** list what parameters the work initially intended to measure.

	Energy	Indoor Climate	Environment (surroundings)
<b>Q</b>	Energy design/Type of energy:	Light:	Resources and emission:
<b>U</b>	Space heating	Day light	Re-use of materials
<b>A</b>	Water heating	Direct sunlight availability	Minimized use of virgin non-renewable materials
<b>N</b>	Ventilation	Surface reflectance	Minimized use of non-renewable fuel resources
<b>T</b>	Cooling and air conditioning	Thermal environment:	Minimize life-cycle emissions of greenhouse gases
<b>I</b>	Electricity for tech. installations	Maximum operative temperature	
<b>T</b>	Electricity for lightning	Minimum operative temperature	
<b>A</b>	Electricity for appliances	Adjustability (individual control)	
<b>T</b>	Natural design solutions:	Indoor air quality:	Characteristics and culture:
<b>I</b>	Passive solar energy	Air change	To be defined in future process
<b>V</b>	Daylight utilisation	Minimum air change	
<b>E</b>	Natural ventilation		
	Shading during cooling season	Acoustics:	
	Integrated solutions	Limit value for inside system noise	
	User behaviour		
	Renewable energy:		
	Energy demand		
	Energy supply		
	Source of renewable energy		

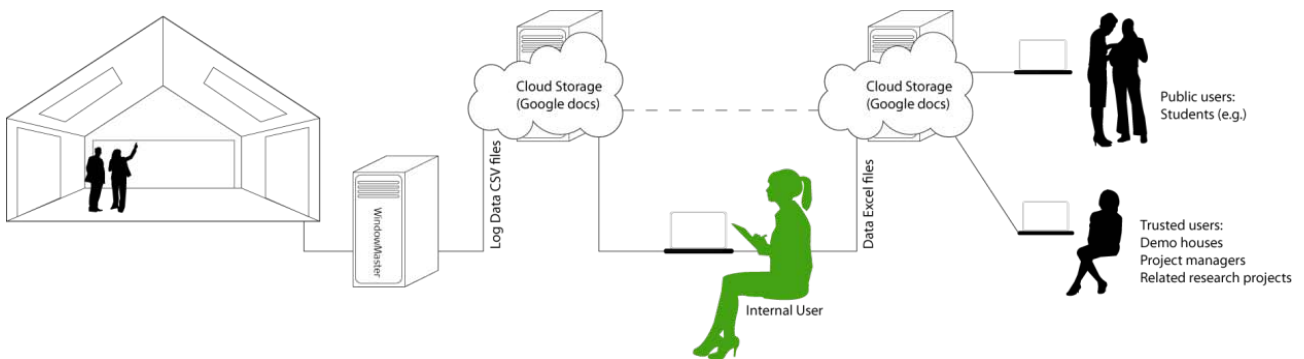
**Ill. 5.2.1 What Parameters Matrix:** The categories Energy, Indoor climate and Environment in the quantitative approach. Source: (Authors' production (Olesen et al. 2011b) based on the Active House Specification (Eriksen et al 2011))

MEASUREMENT	UNIT	DATA FREQUENCY	ROOMS/ZONES	MEASURED BY
<b>ENERGY</b>				
Heat consumption, Space heating	[kWh/60min] [kWh/1440min]	60 minutes	House total	Logged
Heat consumption, Domestic hot water (DHW)	[kWh/60min] [kWh/1440min]	60 minutes	House total	Logged
Heat production, Solar heat plant	[kWh/60min] [kWh/1440min]	60 minutes	Plant total	Logged
Heat production, Heat pump	[kWh/60min] [kWh/1440min]	60 minutes	Pump total	Logged
Electricity consumption, Lighting	[kWh/60min] [kWh/1440min]	60 minutes	Individual light outtakes in rooms	Logged
Electricity consumption, Appliances	[kWh/60min] [kWh/1440min]	60 minutes	House total	Logged
Electricity consumption, Technique	[kWh/60min] [kWh/1440min]	60 minutes	House total	Logged
Electricity production, PV	[kWh/60min] [kWh/1440min]	60 minutes	Plant total	Logged
<b>INDOOR CLIMATE</b>				
Air temperature	[°C]	60 minutes + 15 minutes	All rooms	Sensor on wall
Relative Humidity	[%]	60 minutes + 15 minutes	All rooms	Sensor on wall
CO <sub>2</sub> level	[ppm]	60 minutes + 15 minutes	All rooms	Sensor on wall
Illuminance	[lx]	60 minutes + 15 minutes	All rooms	Sensor on ceiling
Position of solar shading	[% of time step]	60 minutes + 15 minutes	All rooms	WM a system
Position of windows	[% of time step]	60 minutes + 15 minutes	All rooms	WM a system
Presence of occupants (PIR)	[% of time step]	60 minutes + 15 minutes	All rooms	WM a system
Operation of electric light	[% of time step]	60 minutes + 15 minutes	All rooms	WM a system
Operation of windows	[% of time step]	60 minutes + 15 minutes	All rooms	WM a system
Operation of solar shading	[% of time step]	60 minutes + 15 minutes	All rooms	WM a system
<b>ENVIRONMENT</b>				
Air temperature	[°C]	60 minutes + 15 minutes	On location	Weather station
Wind speed	[m/s]	60 minutes + 15 minutes	On location	Weather station
Rain	[mm]	60 minutes + 15 minutes	On location	Weather station
Global illumination	[lx]	60 minutes + 15 minutes	On location	Weather station
Solar radiation	[W/ m <sup>2</sup> ]	60 minutes + 15 minutes	On location	Weather station

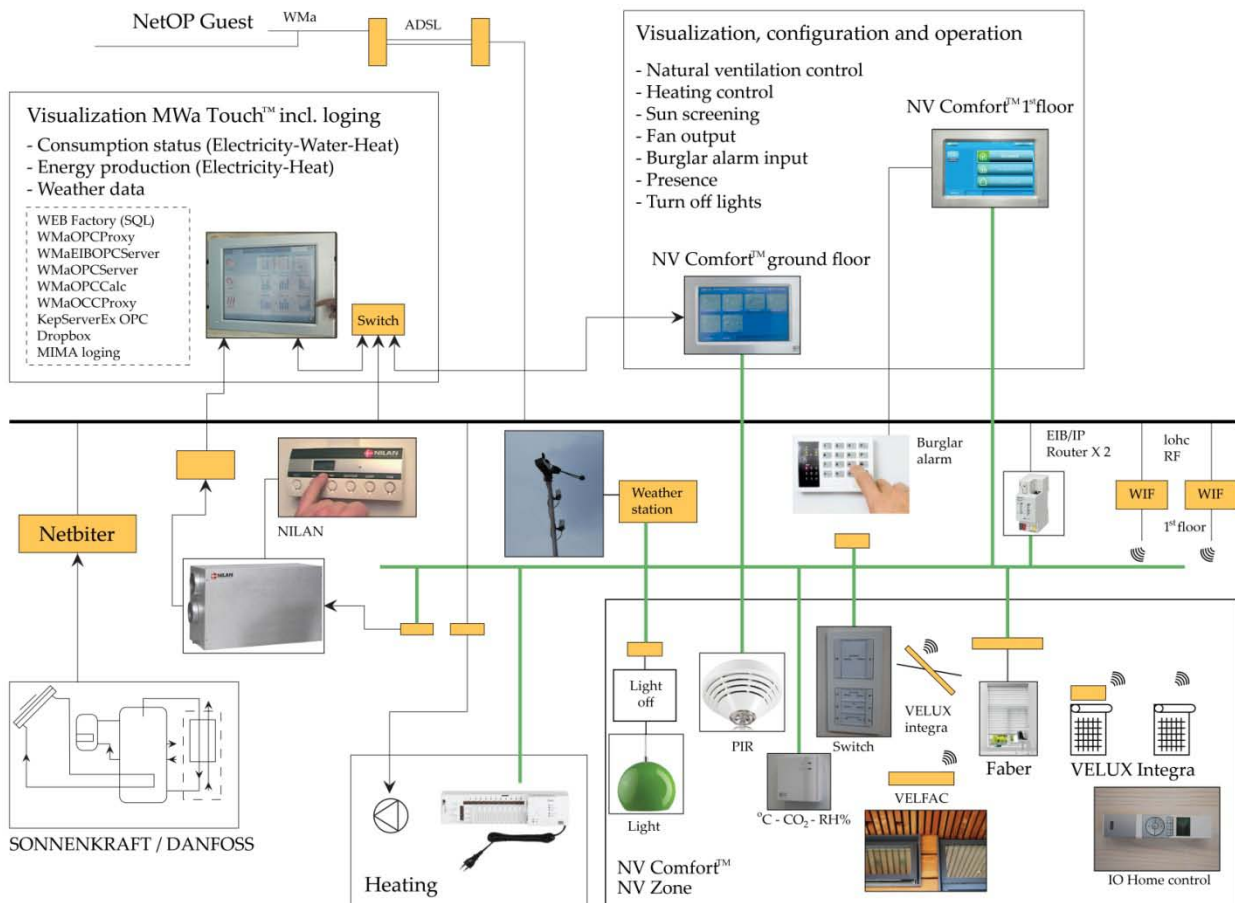
*III. 5.2.2 Data logging overview. The categories Energy, Indoor climate and Environment listed though measurement, unit, data frequency, room/zones and measured by categories.*

### Data collection

Data collection happens through the installed sensors (see ill. 5.2.2. and 5.2.4.) continuously and storage on a local drive. Here after, data are collected to storage cloud from where they can be achieved, quality assured and uploaded to another database, from where they can be retrieved by internal and external parties. (See ill. 5.2.3.)



Ill. 5.2.3 Data collection. The illustration show the process of collecting data from the house through cloud storages.



Ill. 5.2.4. Conceptual diagram of system set up in the house. Made by Gtite Gylling H. Olesen for (Hansen, Olesen & Mullins, 2013)

## Equipment in the houses (examples)

### Technique room



### Sensors and meters



### Measuring weather



## LichtAktiv Haus, Germany, Technical measurement equipment scheme

Meter alias	Meter measuring	På dansk	Comments
Solar_FM1_E	Solar heat		
Solar_FM2_E	Space heating		
Solar_FM3_E	Domestic Hot Water		
Solar_FM4_E	Heat pump		

Meter alias	Meter measuring	På dansk	Comments
KNX_EM1_E	Solar cells	Solceller	
KNX_EM2_E	Lighting	Lysinstallation	
KNX_EM3_E	White goods	Hårde Hvidvare	
KNX_EM4_E	Technique	Teknik	
KNX_EM5_E	Heat pump	Varme anlæg	
KNX_EM6_E	Socket outlets	Stikkontakter	

Electricity for Solar Unit			
KNX_EM08A_E	Light living room ceiling	Lys stue, z.1 (Lampeudtag loft)	
KNX_EM08B_E	Light kitchen ceiling	Lys køkken, z.1 (Lampeudtag loft)	
KNX_EM08C_E	Light outside ceiling	Lys 2+4+Ude (Lampeudtag loft)	
KNX_EM09A_E	Light living room s.o.	Lys stue, z.1 (Lampeudtag stikk.)	
KNX_EM09B_E	Light room West s.o.	Lys værelse 1, z.8 (Lampeudtag stikk.)	
KNX_EM09C_E	Light room East s.o.	Lys værelse 2, z.9 (Lampeudtag stikk.)	
KNX_EM10A_E	Light room West ceiling	Lys værelse 1, z.8 (Lampeudtag loft)	
KNX_EM10B_E	Light room East ceiling	Lys værelse 2, z.9 (Lampeudtag loft)	
KNX_EM10C_E	Light staircase + bathroom ceiling	Lys trappe+bad, z.6+7 (Lampeudtag loft)	

Zone number	Zone name	Floor	Orientation
Zone 1	Living room and kitchen	Ground floor	
Zone 2	Bathroom A	Ground floor	
Zone 3	Technique room	Ground floor	
Zone 4	Tech 2	Ground floor	
Zone 5	Entrance	Ground floor	
Zone 6	Staircase	Ground floor, First floor, Second floor	
Zone 7	Bathroom B	Ground floor	
Zone 8	Room West	Ground floor	
Zone 9	Room East	Ground floor	
Zone 10	Bathroom C	First floor	
Zone 11	Walk-in-closet	First floor	
Zone 12	Bedroom	First floor	
Zone 13	Library	Second floor	

Lux sensors	Zone name	Floor	Orientation
Z01-LUX1	Living room	Ground floor	
Z01-LUX2	Kitchen	Ground floor	
Z08-LUX1	Room West	First floor	
Z09-LUX1	Room East	First floor	

The floor plan illustrates a residential building layout with 13 distinct zones. The zones are distributed as follows:

- Zone 1:** Wohnzimmer (Living Room)
- Zone 2:** Schlafzimmer (Bedroom)
- Zone 3:** Technikraum (Technical Room)
- Zone 4:** Gäste-WC (Guest Toilet)
- Zone 5:** Windfang (Wind Catcher)
- Zone 6:** Central corridor and staircase area.
- Zone 7:** Bad (Bathroom)
- Zone 8:** Zimmer 1 (Room 1)
- Zone 9:** Zimmer 2 (Room 2)
- Zone 10:** Bad (Bathroom)
- Zone 11:** Ankleide (Dressing Room)
- Zone 12:** Schlafzimmer (Bedroom)
- Zone 13:** Additional bedroom area.

Other labeled areas include: Vordach (Canopy), Eingang (Entrance), Terrasse (Terrace), Luftraum (Air Space), and various technical specifications like VELUX Active, KS, and GWS. A north arrow is positioned in the upper right corner of the plan.

## Sunlighthouse, Austria, Technical measurement equipment scheme

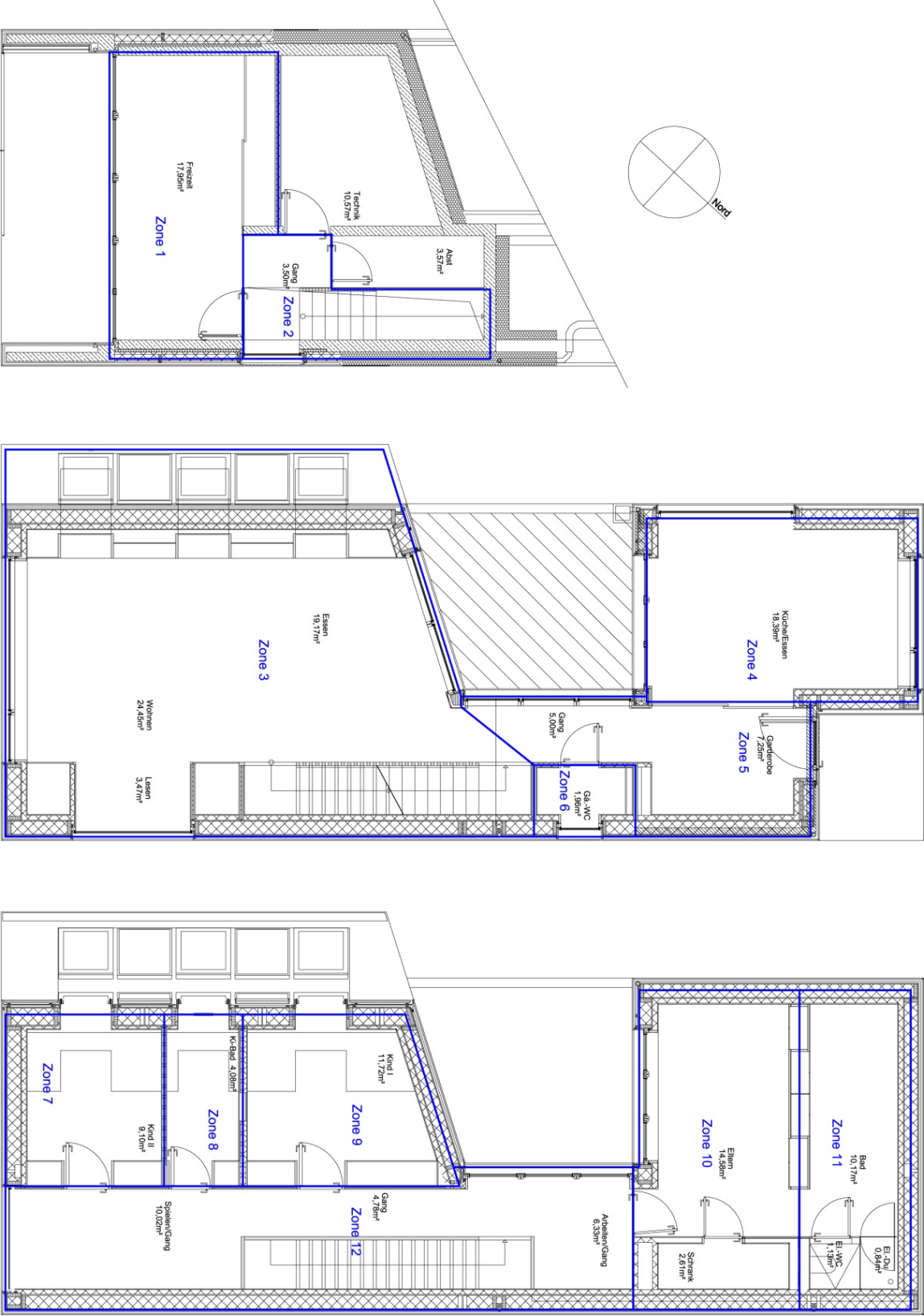
Meter alias	Meter measuring	På dansk	Comments
Solar_FM1_E	Solar heat		Solar heat
Solar_FM2_E	Space heating		
Solar_FM3_E	Domestic Hot Water		
Solar_FM4_E	Earth heat		

Meter alias	Meter measuring	På dansk	Comments
KNX_EM1_E	Solar cells	Solceller	
KNX_EM2_E	Lighting	Lysinstallation	
KNX_EM3_E	White goods	Hårde Hvidvare	
KNX_EM4_E	Technique	Teknik	
KNX_EM5_E	Ventilation	Ventilation	
KNX_EM6_E	Socket outlets	Stikkontakter	
KNX_EM7_E	Equipment	Udstyr til styring	

Electricity for Solar Unit			
KNX_EM08A_E	Light z.1+2+Technique	Lys z.1+2+Teknik	
KNX_EM08B_E	Light kitchen, z.4	Lys køkken, z.4	
KNX_EM08C_E	Light living room, z.3	Lys stue, z.3	
KNX_EM09A_E	Light child room 1, z.9	Lys børneværelse 1, z.9	
KNX_EM09B_E	Light child room 2, z.7	Lys børneværelse 2, z.7	
KNX_EM09C_E	Light child bathroom, z.8	Lys børnebadeværelse, z.8	

Zone number	Zone name	Floor	Orientation
Zone 1	Hobby room	Basement floor	
Zone 2	Hall downstairs	Basement floor	
Zone 3	Living room	Ground floor	
Zone 4	Kitchen	Ground floor	
Zone 5	Entrance	Ground floor	
Zone 6	Bathroom	Ground floor	
Zone 7	Child bedroom A	First floor	
Zone 8	Child bathroom	First floor	
Zone 9	Child bedroom B	First floor	
Zone 10	Parents bedroom	First floor	
Zone 11	Parents Bathroom	First floor	
Zone 12	Work/play hall	First floor	

Sunlighthouse, Austria, P lan with zones indicating technical measurement equipment





Maison Air et Lumière, France, Technical measurement equipment scheme

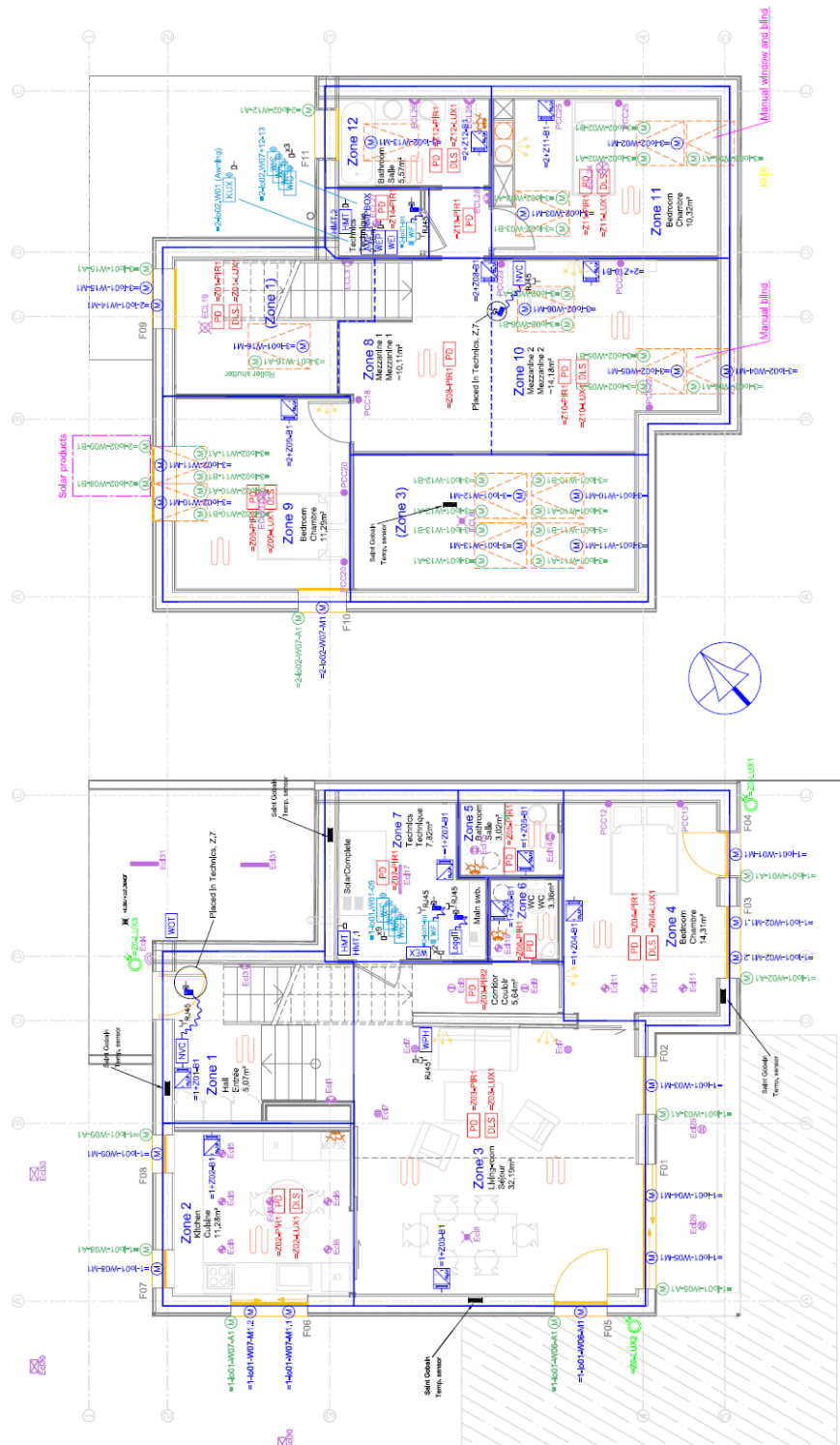
Meter alias	Meter measuring	På dansk	Comments
MBus_QM1_E	Solar heat	Solvarme	
MBus_QM2_E	Space heating	Rumvarme	
MBus_QM3_E	Domestic Hot Water	Varmt brugsvand	
MBus_QM4_E	Heat pump	Varmepumpe	

Meter alias	Meter measuring	På dansk	Comments
KNX_EM1_E	Solar cells	Solceller	
KNX_EM2_E	Lighting	Lysinstallation	
KNX_EM3_E	White goods	Hårde Hvidvare	
KNX_EM4_E	Technique	Teknik	
KNX_EM5_E	Heat unit	Varmeranlæg	
KNX_EM6_E	Socket outlets	Stikkontakter	
KNX_EM7_E	Ventilation	Ventilation	

Electricity for Solar Unit			
KNX_EM08B_E Z01	Stairs, ECL 3 Z01	Trappe, Vægudtag, ECL 3	
KNX_EM08C_E Z01	Hall, ECL 19 Z01	Entre, Loftudtag, ECL 19	
KNX_EM09A_E Z02	Kitchen, ECL 5+6 Z02	Køkken, Loftudtag, ECL 5+6	
KNX_EM09B_E Z03	Below platform, ECL 7 Z03	Stue, Under repos, Loftudtag, ECL 7	
KNX_EM09C_E Z03	Eating area, ECL 8 Z03	Stue, spisebord, Loftudtag, ECL 8	
KNX_EM10A_E Z04	Roof light, ECL 11 Z04	Soveværelse, Loftudtag, ECL 11	
KNX_EM10B_E Z04	Bed light, PCC 12+13 Z04	Soveværelse, Sengelamper, PCC 12+13	
KNX_EM10C_E Z09	Roof light, ECL 21 Z09	Soveværelse, Loftudtag, ECL 21	
KNX_EM11A_E Z09	Bed light, PCC 20 Z09	Soveværelse, Sengelamper, PCC 20	
KNX_EM11B_E Z08	Wall light, PCC 18 Z08	Mezzanine 1, Vægudtag, PCC 18	
KNX_EM11C_E Z10	Wall light, PCC 22 Z10	Mezzanine 2, Vægudtag, PCC 22	
KNX_EM12A_E Z10	Wall light, PCC 23 Z10	Mezzanine 2, Vægudtag, PCC 23	
KNX_EM12B_E Z11	Roof light, ECL 24 Z11	Soveværelse, Loftudtag, ECL 24	
KNX_EM12C_E Z11	Bed light, PCC 25 Z11	Soveværelse, Sengelamper, PCC 25	
KNX_EM08B_E Z12	Bathroom, PCC 26 Z12	Badeværelse, PCC 26	

Zone number	Zone name	Floor	Orientation
Zone 1	Hall	Ground floor	
Zone 2	Kitchen	Ground floor	
Zone 3	Livingroom	Ground floor	
Zone 4	Bedroom 1	Ground floor	
Zone 5	Bathroom	Ground floor	
Zone 6	Toilet	Ground floor	
Zone 7	Technical room	Ground floor	
Zone 8	Mezzanine 1	First floor	
Zone 9	Bedroom 2	First floor	
Zone 10	Mezzanine 2	First floor	
Zone 11	Bedroom 3	First floor	
Zone 12	Bathroom	First floor	
Zone 13	Hall 2	First floor	
Zone 14	Storage room	First floor	

# Maison Air et Lumière, France, Plan, zones indicating technical measurement equipment





## Questionnaire

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The following questionnaire was sent out to the families seasonally and thereby four times during their stay in the houses. The first and fourth time the questionnaire is sent out, it is sent out on its entirety whereas the second and third time only background section and section on indoor environment are sent out.

### Time table overview of questionnaire replies

#### LichtAktiv Haus, Germany

<i>Round and version</i>	<i>Season</i>	<i>Date of reply</i>	<i>Name of replier</i>
Questionnaire #1 Extended version	Summer 2012	12-07-2012	Female
Questionnaire #2 Normal version	Fall 2012	12-11-2012	Male
Questionnaire #3 Normal version	Winter 2013	06-02-2013	Female
Questionnaire #4 Extended version	Spring 2013	06-02-2013	Male

#### Sunlighthouse, Austria

<i>Round and version</i>	<i>Season</i>	<i>Date of reply</i>	<i>Name of replier</i>
Questionnaire #1 Extended version	Summer 2012	18-07-2012	Female
Questionnaire #2 Normal version	Fall 2012	13-11-2012	Female
Questionnaire #3 Normal version	Winter 2013	12-01-2013	Male
Questionnaire #4 Extended version	Spring 2013	20-04-2013	Female

#### Maison Air et Lumière

<i>Round and version</i>	<i>Season</i>	<i>Date of reply</i>	<i>Name of replier</i>
Questionnaire #1 Extended version	Fall 2012	25-10-2012	Female
Questionnaire #2 Normal version	Winter 2013	31-01-2013	Female
Questionnaire #3 Normal version	Spring 2013	12-04-2013	Female
Questionnaire #4 Extended version	Summer 2013	29-06-2013	Female

Please notice that some of the fields for answering possibilities in the 'Background questions' are condensed as to optimize use of space!

## QUESTIONNAIRE

Dear residents,

In the following you will be presented for a number of questions, the questions differ in type, but it is stated whether the questions should be answered by ticking one or more boxes according to what corresponds with your experience etc. For some of the questions it is also possible to elaborate your answers.

The questionnaire is divided in the following subjects:

- Background questions
- Energy
- Indoor climate
- Control units
- Electrical and natural light
- Environment and sustainability

Thank you!

## Background questions

This section will focus on background questions

**Gender (State one answer only)**

☐ Female ☐ Male

**Year of birth (State one answer only)**

☐ 1995 – 1920

Date of filling in this questionnaire (format: DD.MM.YY)\_\_\_\_\_

How large is your family? State number of children (younger than 18 years) (State one answer only)

☐ 0 - 10

State number of adults (18 years or older) (State one answer only)

☐ 0 - 10

Age of children (years) (State only one answer per question)

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

Do you work from home?(State one answer only)

☐ Yes ☐ No

How many hours do you spend indoors at home on...?

...an ordinary working day?<i>Please include night time as well (State one answer only)

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24

☐ ☐

...an ordinary weekend day? <i>Please include night time as well (State one answer only)

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24

☐ ☐

## Energy

*This section will focus on questions regarding energy*

**For each of the following, please state your answer (one answer per question)**

	Yes, very	Yes, to some extent	No, normally not	Don't know
<i>Are you conscious about your energy consumption?</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>Are you conscious about the environmental impact of your daily behaviour?</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>Are you conscious about your heat consumption?</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>Are you conscious about your consumption of hot water?</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>Are you conscious about when you switch on electric light?</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>Has media attention on global warming changed your consciousness about your energy consumption for heating, electric light, etc.?</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

**Please tick to which extent you agree or disagree on the following statements (one answer per question)**

	Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree	Don't know
<i>I always switch on the light at home in good conscience because I know that the PV panels produce sufficient electric power</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>I probably use too much hot water when showering in summer time because I know that the solar thermal collectors produce hot water for free</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

<i>The PV panels and the solar thermal collector on the house are producing all the energy I use at all times</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>I prioritize investing in energy efficient products</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>I have reduced my energy consumption to save money</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

**Please tick to which extent you agree or disagree on the following statements (one answer per question)**

	<i>Strongly agree</i>	<i>Agree</i>	<i>Neither agree nor disagree</i>	<i>Disagree</i>	<i>Strongly disagree</i>	<i>Don't know</i>
<i>It feels good to know that the house produces much of its own energy requirement</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>I probably use too much electricity for light, TV and computers because I know that the PV panels on the house can produce all the power I need</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>The climate changes have altered my behaviour on use of fossil fuels</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>I prefer to spend money on home decoration to investing in energy generating products</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>It is important for me to know that I make an effort to become CO2-neutral</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>My energy consumption has been reduced in consideration of the environment</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>I feel well informed on how to minimize energy consumption</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>



## Indoor Climate

*This section will focus on questions regarding indoor climate*

### Is the quality of the indoor climate important for you? (one answer only)

*Yes, very much*

*Yes, to some degree*

*No, normally not*

*Don't know*

☐
☐
☐
☐

### How do you experience the indoor climate in the house in general and in the rooms mentioned? Tick for each room (one answer per question)

*Very good*

*Good*

*Average*

*Poor*

*Very poor*

*Don't know*

*The house in general*

☐
☐
☐
☐
☐
☐

*Kitchen*

☐
☐
☐
☐
☐
☐

*Living room*

☐
☐
☐
☐
☐
☐

*Bedroom*

☐
☐
☐
☐
☐
☐

### Would you like to change any of the following conditions to make the house more comfortable to live in? Tick several boxes, but not more than 3 (Multiple answers allowed)

- ☐ *No changes*
- ☐ *More daylight*
- ☐ *Better electric lighting*
- ☐ *Better sun screening*
- ☐ *Less draft*
- ☐ *More comfortable indoor temperature*
- ☐ *Better ventilation and airing*
- ☐ *Less noise from the outside*
- ☐ *Other furniture and colours in the house*
- ☐ *Better regulation of the indoor climate*
- ☐ *Less peeping inside from the outside*
- ☐ *Better possibilities for opening and closing windows*

*Other, please specify: \_\_\_\_\_*

**Please evaluate the following (State only one answer per question)**

	<i>Better</i>	<i>Almost the same</i>	<i>Worse</i>	<i>Don't know</i>
<i>Do you experience your health as better or worse compared to as it was in your former home?</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>Do you experience your sleep quality as better or worse compared to as it was in your former home?</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>Do you experience that your children are sleeping better or worse compared to as it was in your former home?</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

**Do you experience that the family have more or fewer sick days compared to as it was in your former home? (State one answer only)**

<i>More</i>	<i>Almost the same</i>	<i>Less</i>	<i>Don't know</i>
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

**How do you evaluate... (State only one answer per question)**

	<i>Excellent</i>	<i>Very good</i>	<i>Good</i>	<i>Less good</i>	<i>Poor</i>	<i>Don't know</i>
<i>...your general health all in all</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>...your sleep quality in general</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

## Control units

*This section will focus on questions regarding control units*

**You can operate the indoor climate by either the remote control, the screen or manually. Which control unit do you use most often to operate the indoor climate in the house? (one answer per question)**

	<i>1 - Most used unit</i>	<i>2 - 2nd most used unit</i>	<i>3 - Least used unit</i>
<i>Operate by SCREEN</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>Operate by REMOTE CONTROL</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>Operate MANUALLY</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

**How often do you check the house's energy production... (State only one answer per question)**

	<i>Never</i>	<i>Weekly</i>	<i>Several times a week</i>	<i>Daily</i>	<i>Several times daily</i>	<i>Don't know</i>
<i>...for hot water on the control unit(s)?</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>...for electricity on the control unit(s)?</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

**To which degree are you satisfied or dissatisfied with the way the house systems are operated by the control units? (State only one answer per question)**

	<i>Very satisfied</i>	<i>Satisfied</i>	<i>Neither satisfied nor dissatisfied</i>	<i>Dissatisfied</i>	<i>Very dissatisfied</i>	<i>Don't know</i>
<i>Facade windows</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>Roof windows</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

<i>Indoor temperature</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>Internal screening of facade windows</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>Internal screening of roof windows</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>External screening</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>Ventilating system</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

**Does the way the control units operate the house systems support your needs? (State one answer only)**

*Yes, very*

*Yes, to some degree*

*No, normally not*

*Don't know*

☐
☐
☐
☐

**How do you find the usage of the control units? (State only one answer per question)**

*Very easy to use*

*Easy to some extent*

*Somewhat difficult*

*Very difficult to use*

*Don't know*

*The screen* ☐ ☐ ☐ ☐ ☐

*The remote control* ☐ ☐ ☐ ☐ ☐

**During the last couple of weeks, how often have you used either the screen and/or the remote control to operate the house systems? (State only one answer per question)**

*Very rarely*

*Rarely*

*Occasionally*

*Frequently*

*Very frequently*

*Don't know*

*Facade windows* ☐ ☐ ☐ ☐ ☐ ☐

<i>Roof windows</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>Internal temperature</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>Internal screening of facade windows</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>Internal screening of roof windows</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>External screening</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>Ventilating system</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

**How do you prefer to operate the following? Would you use either the screen/remote control, operate manually or use both options? (one answer per question)**

	<i>Use screen/remote control</i>	<i>Do it manually</i>	<i>Use both</i>	<i>Don't know</i>
Facade windows	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Roof windows	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Indoor temperature	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Internal screening of facade windows	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Internal screening of roof windows	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
External screening	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Ventilating system	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

## Electric Light

*This section will focus on questions regarding electric light only*

**Compared to your former home, do you now have to turn on electric light more or less often? (one answer per question)**

	<i>More often</i>	<i>Approx. the same</i>	<i>Less often</i>	<i>Don't know</i>
<i>Kitchen</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>Living room</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>Bedroom</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

**How do you in general evaluate the level of electric light in the following rooms? (one answer per question)**

	<i>Not enough light</i>	<i>Appropriate</i>	<i>Too much light</i>	<i>Don't know</i>
<i>Kitchen</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>Living room</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>Bedroom</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

**Please state how satisfied or dissatisfied you are with the electric lighting in the house in general and in the following rooms. (one answer per question)**

	<i>Very satisfied</i>	<i>Satisfied</i>	<i>Neither satisfied nor dissatisfied</i>	<i>Dissatisfied</i>	<i>Very dissatisfied</i>	<i>Don't know</i>
<i>The house in general</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>Kitchen</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>Living room</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>Bedroom</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

## Daylight

This section will focus on questions regarding daylight

**Compared to your former home, do you experience the daylight level in your present house as (one answer only)**

<i>Much higher</i>	<i>Higher</i>	<i>Almost the same</i>	<i>A little less</i>	<i>Much less</i>	<i>Don't know</i>
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

**How do you in general evaluate the level of daylight in the following rooms? (one answer per question)**

	<i>Not enough daylight</i>	<i>Appropriate</i>	<i>Too much daylight</i>	<i>Don't know</i>
<i>Kitchen</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>Living room</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>Bedroom</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Please state how satisfied or dissatisfied you are with the daylight in the house in general and in the following rooms: (one answer per question)

	<i>Very satisfied</i>	<i>Satisfied</i>	<i>Neither satisfied nor dissatisfied</i>	<i>Dissatisfied</i>	<i>Very dissatisfied</i>	<i>Don't know</i>
<i>The house in general</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>Kitchen</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>Living room</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>Bedroom</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

## Direct Sunlight

Would you like direct sunlight to enter in the following rooms at certain times of the day? Multiple answers are allowed

### ...Kitchen (Multiple answers allowed)

No	Yes, in the morning	Yes, at noon	Yes, in the afternoon	Yes, in the evening	Don't know
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

### ...Living room (Multiple answers allowed)

No	Yes, in the morning	Yes, at noon	Yes, in the afternoon	Yes, in the evening	Don't know
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

### ...Bedroom (Multiple answers allowed)

No	Yes, in the morning	Yes, at noon	Yes, in the afternoon	Yes, in the evening	Don't know
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

### Are you sometimes bothered by direct sunlight in the following rooms? (one answer per question)

	Very rarely	Rarely	Occasionally	Frequently	Very frequently	Don't know
Kitchen	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Living room	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Bedroom	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

### Do you think that the windows in the following rooms are: (State only one answer per question)

	Too large	About right	Too small	Don't know
Kitchen	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Living room	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>



Bedroom

☐☐☐☐

## Temperature

*This section will focus on questions regarding temperature.*

**State how satisfied or dissatisfied you are with the temperature conditions in the house in general and in the following rooms: (one answer per question)**

	<i>Very satisfied</i>	<i>Satisfied</i>	<i>Neither satisfied nor dissatisfied</i>	<i>Dissatisfied</i>	<i>Very dis- satisfied</i>	<i>Don't know</i>
<i>The house in general</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>Kitchen</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>Living room</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>Bedroom</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

**How have you experienced the temperature conditions in the following rooms during the last couple of weeks? (one answer per question)**

	<i>Too hot</i>	<i>About right</i>	<i>Varying</i>	<i>Too cold</i>	<i>Don't know</i>
<i>Kitchen</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>Living room</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>Bedroom</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

**Have you experienced varying temperature conditions in the following rooms? (one answer per question)**

	<i>Yes, very</i>	<i>Yes, to some degree</i>	<i>No, normally not</i>	<i>Don't know</i>
<i>Kitchen</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

<i>Living room</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>Bedroom</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

### How often do you experience the following? (State only one answer per question)

	<i>Very rarely</i>	<i>Rarely</i>	<i>Occasionally</i>	<i>Frequently</i>	<i>Very frequently</i>	<i>Don't know</i>
<i>Being bothered by varying temperatures in the house</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>Experience draughts from the windows</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

## Air quality, sound/acoustics & view

*This section will focus on questions regarding air quality, sound/acoustics & view*

### How have you experienced the air quality in the house during the last couple of weeks? (State one answer only)

<i>Very acceptable</i>	<i>Acceptable</i>	<i>Neither acceptable nor unacceptable</i>	<i>Unacceptable</i>	<i>Very unacceptable</i>	<i>Don't know</i>
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

**Have you experienced any problems with the air quality being** <i>Multiple answers are allowed  
(Multiple answers allowed)

*Stuffy*

☐

*Unpleasant*

☐

*Dry*

☐

*No, I haven't experienced  
any problems*

☐

*Other, please specify:* \_\_\_\_\_

**What do you usually do if you want to improve the air quality?** <i>Multiple answers are allowed  
(Multiple answers allowed)

*Adjust the  
ventilating unit*

☐

*Open facade  
windows*

☐

*Open roof  
windows*

☐

*Make draught*

☐

*Nothing*

☐

*I never need to  
improve air  
quality*

☐

*Other, please specify:* \_\_\_\_\_

**State how satisfied or dissatisfied you are with the sound and acoustics conditions in the house (State one answer only)**

*Very satisfied*

☐

*Satisfied*

☐

*Neither satisfied  
nor dissatisfied*

☐

*Dissatisfied*

☐

*Very dissatisfied*

☐

*Don't know*

☐
☐

**Are you at all bothered by the sound of the systems?**

**(State only one answer per question)**

	<i>Yes, very much</i>	<i>Yes, to some degree</i>	<i>No, normally not</i>	<i>Don't know</i>
<i>Facade windows</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>Roof windows</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>Internal screening</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>Ventilating system</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

**How important do you think that the view through the windows is? (State one answer only)**

<i>Very important</i>	<i>Quite important</i>	<i>Fairly important</i>	<i>Slightly important</i>	<i>Not at all important</i>	<i>Don't know</i>
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

**State how satisfied or dissatisfied you are with the view through the windows in the house in general and in the following rooms: (State only one answer per question)**

	<i>Very satisfied</i>	<i>Satisfied</i>	<i>Neither satisfied nor dissatisfied</i>	<i>Dissatisfied</i>	<i>Very dissatisfied</i>	<i>Don't know</i>
<i>The house in general</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>Kitchen</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>Living room</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>Bedroom</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

## Environment and Sustainability

*This section will focus on questions regarding environment and sustainability*

### What do you think about the location of the house on the site? (Multiple answers allowed)

*The location is  
right*

☐

*It is too close to  
the neighbours*

☐

*It is too close to  
roads*

☐

*Wrong location in  
relation to day-  
and sunlight*

☐

*Right location in  
relation to day-  
and sunlight*

☐

*Don't know*

☐

### In your opinion, does the house fit into the neighbourhood? (State one answer only)

*Yes, very*

☐

*Yes, to some degree*

☐

*No, it stands out*

☐

*Don't know*

☐

### Do you think that we shall see more houses like the one you live in in the next 20 years? (State one answer only)

*Yes, I think it will be  
quite normal*

☐

*Yes, to some degree*

☐

*No, not many*

☐

*No, not at all*

☐

*Don't know*

☐

### What was your immediate impression of the house when you first saw it? <i>Multiple answers are allowed (Multiple answers allowed)</i>

*Futuristic*

☐

*Energy*

☐

*Eco-consciousness*

☐

*Good architecture*

☐

*Good location*

☐

*Beautiful house*

☐

*Other, please specify: \_\_\_\_\_*

### What do you think about the signaling value of using energy technologies (PV panels and solar thermal collectors) on the outside of the house? (one answer only)

*Very good*

☐

*Good*

☐

*Neither good nor  
bad*

☐

*Bad*

☐

*Very bad*

☐

*Don't know*

☐

**Do you find that the energy producing units, PV panels and solar thermal collectors, have been well integrated in the design of the house? (one answer per question)**

	<i>Very good</i>	<i>Good</i>	<i>Neither nor bad</i>	<i>good</i>	<i>Bad</i>	<i>Very bad</i>	<i>Don't know</i>
PV panels (electricity)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Solar thermal collectors (heating and hot water)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

**Is it possible to make architecturally attractive houses with elements such as PV panels and solar thermal collectors? (one answer only)**

<i>Yes, absolutely</i>	<i>Yes, to a certain degree</i>	<i>No, I do not think so</i>	<i>Don't know</i>
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

**Do you think that the house you live in is an example of an architecturally attractive house? (one answer)**

<i>Yes, absolutely</i>	<i>Yes, to a certain degree</i>	<i>No, I do not think so</i>	<i>Don't know</i>
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

**Are you concerned about minding the environment? (one answer only)**

<i>Very concerned</i>	<i>Concerned</i>	<i>Neither / nor</i>	<i>Not concerned</i>	<i>Not at all concerned</i>	<i>Don't know</i>
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

**Are you concerned about saving energy? (one answer only)**

<i>Very concerned</i>	<i>Concerned</i>	<i>Neither / nor</i>	<i>Not concerned</i>	<i>Not at all concerned</i>	<i>Don't know</i>
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

**Do you have any comments, what so ever - please feel free to share them**

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**Thank you for your help: We thank you again for your participation**

## Blog

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*Blog data are collected off the individual houses homepages. Below, links to these pages are referred. The respective pages also contain basic information about the families and houses in general.*

### Model Home 2020 - references to house homepages

#### **LichtAktiv Haus**

Dorfsetter, L. & Dorfsetter, Y. 2012, 2013/03/02-last update, *Sunlighthouse* [Homepage of VELUX], [Online]. Available: <http://www.sunlighthouse.at/cat/familie/> [2013, 10/31].

#### **Sunlighthouse**

Oldendorf, C. & Oldendorf, I. 2013, 2013/10/31-last update, *LichtAktiv Haus - Die Familie Interaktiv* [Homepage of VELUX], [Online]. Available: <https://lichtaktivhaus.de/> [2013, 10/31].

#### **Maison Air et Lumière**

Pastour, F. & Pastour, S. 2013, 2013/07/25-last update, *Habiter La Maison De Demain* [Homepage of VELUX], [Online]. Available: <http://www.maisonairtlumiere.fr/index.php/les-carnets-de-chantier/> [2013, 10/31].





## In-situ research

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A *scheme for collection, treatment and dissemination* of perceived quality in sustainable homes is compiled aiming at forming a more tangible framework for being aware of such elements in enquiry of sustainable buildings. The scheme be found in the article Enquiring Sustainable Homes: A More Tangible Approach (Olesen & Knudstrup, 2013b).

The composed scheme is compiled with intention to structure collection, treatment and dissemination of data. The scheme illustrates *Motif* (photo), *Worth* (description) and *Extent* (rating accordingly Likert scale (Likert, 1931)). Application of the scheme shows that that the three categories enquiry supports each other well by illustrating each element from different perspectives and thereby the three supplement each other. *Extent* ratings are based on the following scale: I) Yes, very much; II) To a wide extent; III) Neither/Nor; IV) No, not really; V) No, not at all

Registration scheme	Motif	Worth	Extent
<b>PERCEPTION</b>			
<i>Sensuous encounters</i>			
<i>Perceived indoor environment</i>			
<i>Perceived air quality</i>			
<i>Perceived thermal environment</i>			
<i>Perceived aural environment</i>			
<b>SURROUNDINGS</b>			
<i>Orientation and integration</i>			
<i>Relation to nature</i>			
<i>Connection and transition</i>			
<i>Visual privacy</i>			
<i>Views</i>			
<b>COMPOSITION</b>			
<i>Shape of house and spaces</i>			
<i>Impressions and signals</i>			
<i>Composition and proportions</i>			
<i>Construction, joints and details</i>			
<i>Characteristics</i>			
<b>SURFACE</b>			
<i>Membrane expression</i>			
<i>Abilities of surfaces</i>			
<i>Reflectance and transparency</i>			
<i>Tactility of surfaces</i>			
<i>Colours of surfaces</i>			
<b>LIGHT &amp; SHADOW</b>			
<i>Light and shadow</i>			
<i>Brightness and darkness</i>			
<i>Anatomy of light</i>			
<i>Light space</i>			
<i>Filtering and temporality</i>			
<b>VARIABILITY</b>			
<i>Perceived variability</i>			
<i>Dynamics and movement</i>			
<i>Time</i>			
<i>Durability</i>			
<i>Patina and ageing</i>			
<b>UTILITY</b>			
<i>Plan functionality</i>			
<i>Everyday use</i>			
<i>Automation</i>			
<i>Interiority elements</i>			

