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# Designing Holistic Zero Energy Homes in Denmark

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## Abstract

*There is an increased interest for zero-energy buildings (ZEB), however, designing ZEBs is still challenging. In order to gain further currency, we need to collect and communicate research-based knowledge in an easy applicable way for the building industry. This paper presents the process of developing a ZEB design guide with a long-term perspective heading towards 2035 building design and targeting practicing architects, engineers and developers. The publication introduces a number of design strategies and technologies which are particularly important for the development of zero energy houses, and identifies technical and architectural potentials and challenges related to the application of these. The publication argues that the key issue is to design the buildings through a cross-disciplinary approach to architecture and based on an integrated design process.*

*The project is part of the Danish Strategic Research Centre for Zero Energy Buildings at Aalborg University, Denmark.*

***Keywords - Holistic zero energy building design, architecture, design principles, cross-disciplinary design, integrated design***

## 1. Introduction

Realization of the Danish vision to be a society independent on fossil fuels by 2050, as stated in the Danish Government's Climate plan from 2013 [1] and Energy strategy 2050 from 2011 [2], calls for significant energy efficiency and increased renewable energy production in the years to come. According to article 9 of the EU Directive 2010 *on the energy performance of buildings*, member states shall ensure that by 2020 "all new buildings are nearly zero-energy buildings" [3].

A number of projects [4, 5] demonstrate that it is possible to design buildings with a very low energy need and an energy production that balances the (low) energy use on a yearly basis, e.g. the six VELUX Model Home 2020 [6]. However, designing ZEBs is still not common practice. Many of the projects are demonstration projects designed by design teams of experts and specialists, updated with the newest knowledge, including new technologies, within sustainable building design. These demonstration projects try to show the direction for detached houses of tomorrow. This, however, requires that knowledge and experiences are collected and made applicable for the building industry. Furthermore, much research done within the theme of energy efficient buildings focus

on specific aspects, e.g. [7, 8, 9] and is usually published as scientific articles which, at times, can be hard to acquire and may be difficult to read by people outside the scientific society. All in all, new knowledge can appear rather fragmented, and it may require considerable time and effort to get an overview and to clarify how the information can be applied in practice. Current paper addresses this problem and presents the process of developing the design guide entitled “Zero Energy Buildings – Design Principles and Built Examples for Detached Houses” [10]. The design guide targets practicing architects, engineers in the building industry and the active developer, and is one in a series of three publications published by the Danish Strategic Research Centre for Zero Energy Buildings.

## 1.2 Background and ZEB definition

The Danish Strategic Research Centre for Zero Energy Buildings ([www.zeb.aau.dk](http://www.zeb.aau.dk)) was established in 2009 at Aalborg University by a grant from the Danish Council for Strategic Research (DSF), the Programme Commission for Sustainable Energy and Environment, and in cooperation with Danish research institutions, universities, private companies, and the public sector. The Centre counts researchers in the field of architecture and engineering, and a Centre Advisory Board, which includes public authorities, organizations, building owners, private companies, consulting engineers and architects. At the moment, no standardized definition of ZEBs exists. In the Danish Strategic Research Centre for ZEBs, there have been made a state-of-the-art on ZEB definitions and it discovered more than ten definitions [11]. In order to be able to approach the design of new ZEBs, the Danish Strategic Research Centre for ZEBs has formulated following overall definition of ZEBs:

*“Zero Energy Buildings (ZEB) are buildings designed with a low energy demand and that energy demand is covered by fossil free energy sources. It is thus based on an optimal combination of energy savings and supply of renewable energy from electrical, thermal and/or biogas networks or from on-site renewable energy systems.*

*Zero Energy Buildings also have a very good indoor environment with respect to temperature, air quality, daylight and acoustics, as well as a high architectural quality and designed with respect for the user.*

*The goal is to eliminate the problems of using fossil energy by changing to a fully fossil free energy system. Solutions should primarily be designed considering the long-term perspective, but solutions should also consider the transition of the existing energy system to the future energy system. The optimal solution will depend on the given context.” [10]*

Thus, the research center clearly emphasizes the importance of holistic solutions where architecture, comfort, indoor environment, energy and user behavior are integrated parts of an unified building concept, and where the building is designed on the basis of the specific context’s potentials and challenges. The aim thus is to clarify what form and content the design guide should have in order to communicate essential design and research-based knowledge of holistic ZEB design in a simple and comprehensible way.

## 2. Methodological approach

The Integrated Design Process (IDP) formulated by Knudstrup [12,13,14] forms the methodological framework. The development of the design guide is based on own research and experiences with using the IDP, literature studies, input from researchers of the center and the cross-disciplinary Advisory Board. Moreover, along the process the design guide has been discussed with target group representatives.

As basis for the development of the design guide, the following two sections presents two preliminary studies that have been made, partly of the working process of the target group and partly a review of existing design guides.

## 3. From Traditional Working Methods to Interdisciplinary Cooperation and Integrated Design

A close collaboration between architects and engineers from the very beginning of an IDP seems to be generally accepted as a basis for energy efficient building design, as exemplified in [14,15,16,17,18]. However, targeting both architects and engineers at the same time, calls for particular considerations in regard to form, content, and language of the design guide. Although sharing the overall field of work, i.e. the built environment, architects and engineers, traditionally, have very different focus, approach to design, working methods, and language, a topic that have been discussed by several, among others [16,18,19,20].

Based on his observations of “how professionals think in action” [21] Schön describes the architect’s design process as a “reflective conversation with the situation” – a process where the architect reflects on (good and bad) solutions and continues the work based on these reflections. Schön defines this approach as “reflection-in-action” [22]. His studies, furthermore, illustrate that the development of design proposals necessitates a combination of verbal and non-verbal (sketching, modelling, etc.) communication that supports each other. By comparison, Schön describes the work process of the engineer as a “threefold *mapping* of the signs of the present situation onto known problems and techniques” [23].

However, according to Schön, the approach and design process of the engineer changes when the engineer faces new and unique challenges that do not fit into the “known” categories. In that case, the design process of the engineer will be similar to the “reflective conversations with the situation” of the architect [24]. Trebilcock draws a similar conclusion from her case studies of the design process of architectural practices that are pioneers in integrating sustainability issues and low energy strategies by stating that “the architect and the engineer would proceed in a similar manner, sharing the character of designer” [25]. Trebilcock, furthermore, states that the integrated approach to design requires that “the architect needs to develop knowledge in architectural sciences and skills in simple environmental analysis, while the engineer needs to develop knowledge in architectural matters and skills in design.” [26].

Facing the complex task of designing holistic ZEBs, where both architectural and engineering knowledge must be implemented from the very beginning of the design process to develop, test, and refine the design, it may be reasonable to assume that the

two professions' approach in the design process will proceed in a more similar manner than traditionally seen, and the design guide may advantageously focus on the similarities of the two groups, namely that of being a designer. Accordingly, three overall guiding principles for the design guide were formulated and subsequently refined after dialogue with target group representatives. The three guiding principles are:

- The knowledge communicated in the design guide should be in a level and language that cover basic and essential knowledge of both professions and, hereby, give the architect insight into the knowledge and design challenges of the engineer, and vice versa.
- The information in the booklet must be able to influence the designers at the early stages of the design process
- The information may advantageously be a combination of words and illustrations.

#### **4. Existing Design Guides for Energy Efficient Building Design**

In the preface of the project, a review of existing design guides has been done in order to see what already exist in the field. Examples of design guides for energy efficient building design are [27,28,29], which range from guidelines to checklists and specific building concepts, e.g. the Passive House concept [29]. Additionally, a review of three design guides: Integrated Design Process – A Guideline for Sustainable and Solar-Optimised Building Design [16], Integrated Energy Design – Some Principles of Low Energy Building Design [30], Inspiration Guide for Environmental Design [31] were conducted, in order to study different approaches for overall structure, focus areas, format, combination of visual material and text, ways to address target groups, etc. The three design guides provide guidelines and checklists for the design of low energy buildings. The IDP guideline from IEA task 23 [16] is, primarily, focusing on the process and the cross-disciplinary approach to design. In the IED guide [30], the combination of text and principle diagrams ease the understanding of the different principles which can be applied through the process. In the *Inspiration Guide for Environmental Design* [31], the concise sum up of important aspects to consider during the process provides an easy applicable “reminder” without pointing at pre-defined solutions. These elements have been used as inspiration for the further development of the design guide presented in this paper. The review of the three existing design guides also clarified that a further elaboration and illustration of possible ways to integrate different strategies in the design could be desirable. In all three cases, the design guide is a limited number of pages, and the format is based on being a working tool for practice. This is also in line with the requests of the Advisory Board related to the Danish Strategic Research Centre for ZEBs.

Due to the holistic and context related approach to ZEB design, as specified in the research centers ZEB definition, it was decided that the design guide should not present a predefined building concept but focus on providing a profound cross-disciplinary knowledge foundation that should support the IDP and collaboration between the different professions.

## 5. Results

Based on the above studies the design guide “Zero Energy Buildings – Design Principles and Built Examples for Detached Houses” [10] was developed. The design guide was continuously refined based on dialogue with several target group representatives. The final approach and strategy for form and content is presented in the following sections.

### 5.1 Overall strategy

Designing a holistic ZEB is a complex task with many parameters in play (Fig. 1) – parameters that are often interconnected or even conflicting. It requires a fine balance between the many design parameters if the building is to meet the strict requirements for energy and indoor environment without having to compromise on the qualitative aspects.

As each design project is unique regarding context, users, etc., the design guide does not suggest an all-covering concept with a fixed set of solutions, but focuses on providing a comprehensive cross-disciplinary basis for the design team to draw the best set of solutions for the given project. This is done through a clarification and articulation of strategically selected design strategies and technologies which are of vital importance to the development of new holistic zero energy detached houses. By this, the design guide seeks to open a dialog between the active developer, practicing architects and engineers and, hereby, bridge the gap between professions.

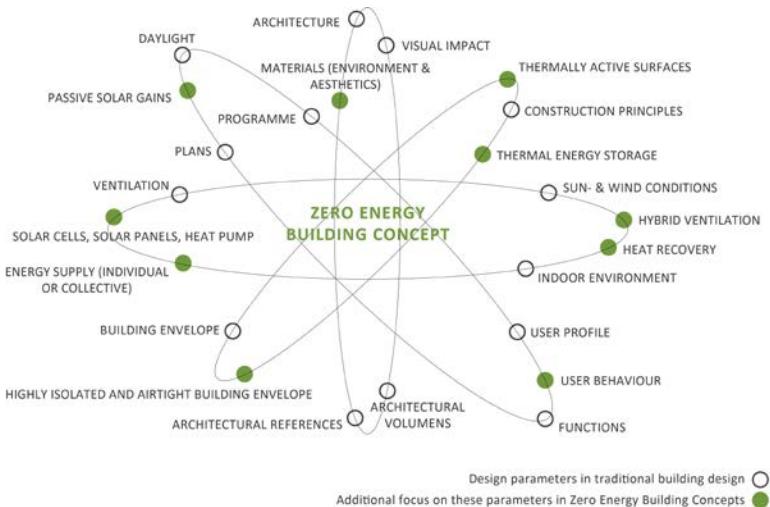


Fig. 1 Essential design parameters at play in an integrated design process. Diagram design based on [12].

The design strategies and technologies are presented in three main sections, related to: 1) the project framework, 2) the overall building design and context, and 3) related to energy supply. The design strategies and technologies are presented separately but are, of course, deeply interrelated and, sometimes, even conflicting. Hence, it is most vital always to examine and evaluate/document the specific combination of design strategies and technologies in each given project, in relation to both architecture and technical performance of the building. As the purpose of the design guide is to support the IDP and co-operation between these two professions, the subject areas are described at a general level, to provide the engineer with an insight into the techniques used by the architect, and vice versa. Additionally, specialist knowledge must be obtained, depending on the given project.

## 5.2 Layout

The design guide is intended as a reference book that can provide inspiration from the early design phases. One may read the design guide from start to end in order to get an overview, or look up specific design strategies and technologies depending on where you are in the design process and what (specific) design task one faces. Early in the process, it was decided that the design guide should be concise and provide hands-on knowledge based on the argument that, in practice, there is no time to read lengthy and comprehensive explanations. A maximum of 60 pages provide an overall frame of the design guide. Each design strategy and technology is given one full spread, and is unfolded through a number of graphically easy identifiable icons (see Fig. 2) in order to ensure consistency throughout the design guide and to make the information easily accessible. Through a combination of text and visual representations the design guide illustrates how this knowledge can be applied.

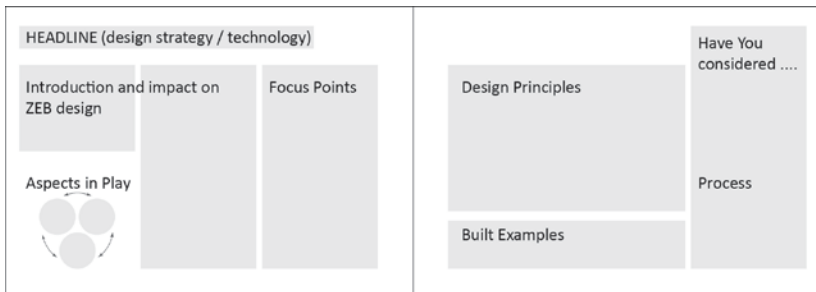


Fig. 2 Layout of a spread presenting a design strategy or technology

## 5.3 Content

Besides an introduction to and general knowledge about the design strategy/technology, the spread presents “Aspects in Play”, “Focus Points”, “Design

Principles”, “Built Examples” and sum up with “Have you Considered” and “Process”. These eight “perspectives” are elaborated in the following.

### *Introduction and impact on ZEB design*

Each design strategy/technology is shortly introduced, and it is elaborated how the cross-disciplinary knowledge can be used strategically in creating ZEBs, and its impact on the ZEB design is outlined. An example is solar shading as an essential design strategy, and the introduction to this could include, among others:

*We know that if we design in order to have sufficient and good daylight conditions there will, occasionally, be too much – resulting in either overheating or glare. Therefore, it is necessary to integrate a form of solar shading. Generally, we distinguish between two types of solar shading: 1) Interior solar shading – to adjust daylight, and 2) Exterior solar shading – to reduce heat gains. According to Jensen & Petersen’s article from 2013 [32], an exterior solar shading is essential in order to meet the requirements for energy demands for a Building class 2020 (according to the Danish Building regulation from 2010) [33] and, at same time, ensure good daylight conditions in the home.*

### *Aspects in Play*

In order to bridge the gap between actors and to facilitate the integrated design, this section states different means one can work with in relation to the specific design strategy/technology, as well as qualitative and quantitative aspects that the solution should be evaluated by. For example when designing solar shading for a ZEB one should consider different types of shading depending on the needs it should fulfill according to indoor environment, energy, aesthetic requests for the design and user behavior. These different means are then evaluated considering both quantitative and qualitative aspects. Examples could be:

- *Means: e.g. fixed lamellae (vertical or horizontal), automatic or manual control, sunlight protected window panes and vegetation*
- *Quantitative aspects: impact on the daylight factor; light transmittance; overheating; and impact on energy need*
- *Qualitative aspects: façade expression; spatial experience; view and privacy; and daylight quality (color, contrasts, risk of glare, and daylight path over the day/year).*

### *Focus Points*

As each project is unique regarding climate condition, context, users, etc., the focus is on clarifying the various aspects the designers (engineers and architects) should be aware of when applying the specific design strategy/technology in ZEB design – and in particular knowledge related to the early stages of the design process. Examples of “Focus Points” when designing the solar shading are:

- *Impact on spatial experience*
- *The orientation of the room in relation to its function*
- *View and privacy*
- *Overheating and glare*
- *Impact on quality of light and light conditions in the room*
- *Requirements to daylight factor/lux in building regulations*



- *Facade expressions*
- *Control - manual or automatic (users should feel they are not losing control)*

### *Design Principles*

The design strategies and technologies are unfolded through simple design principles that illustrate different “space of solutions”. The design principles exemplify how the design strategy/technology in different ways can form an integrated part of a building concept. Often, there is not one general (best) solution but several possible, and it will always depend on the given project, i.e. the context, the users, demands to comfort, energy, economy, etc. The design principles are further elaborated by specific aspects to be aware of, which can support a comparison of the different design principles.

### *Built Examples*

Photographs of built projects exemplify how some of the design principles could be integrated in practice. The purpose of these is to supplement the diagrammatic design principles and provide the design team a common frame of reference.

### *Have You Considered...*

Main sections (1-2 spreads) are concluded with a fact box that sums up key points in short form. The main sections refer to either one overall design strategy/technology or to a couple of interrelated strategies/technologies.

### *Process*

Main sections are also concluded by a short description that relates the design strategy/technology to the IDP. Based on three overall design phases: Phase 1: *Defining Design Criteria*; Phase 2: *Sketching, evaluating and optimizing the project*, and Phase 3: *Concretizing the project*, the design guide suggests what level of knowledge regarding the specific design strategy/technology that should be considered in the different phases.

## **6. Conclusion**

This paper has presented the process of developing a design guide that gathers and communicates research-based knowledge within ZEB design to practicing architects, engineers and developers, focusing on design of zero energy homes in Denmark. The objective of the design guide has been two-fold, i.e. to bridge the gap between theory and practice and to bridge the gap between different professions.

The design guide unfolds strategically selected design strategies and technologies which are essential for the design of zero energy homes. These are unfolded through the perspectives “Introduction and its relation to ZEB” “Aspects in play”, “Focus Points”, “Have you considered...” and “Process”, “Design Principles” and “Built Examples”. By presenting relatively simple illustrations and short essential information the reader is made aware of central issues to be considered, regarding technical, aesthetic and functional aspects of holistic ZEB design. Via this pragmatic approach the design guide

seeks to facilitate and demystify the otherwise complex task of designing holistic ZEBs. Hereby, the design guide provides a wide cross-disciplinary foundation and transfer of knowledge and, hereby, facilitates the integrated design process and, hopefully, eases the cross-disciplinary cooperation between the primary actors, i.e. the architects, engineers and the developer.

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