Zero Energy Buildings – Design Principles and Built Examples

for Detached Houses

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Publication date:
2014

Document Version
Publisher's PDF, also known as Version of record

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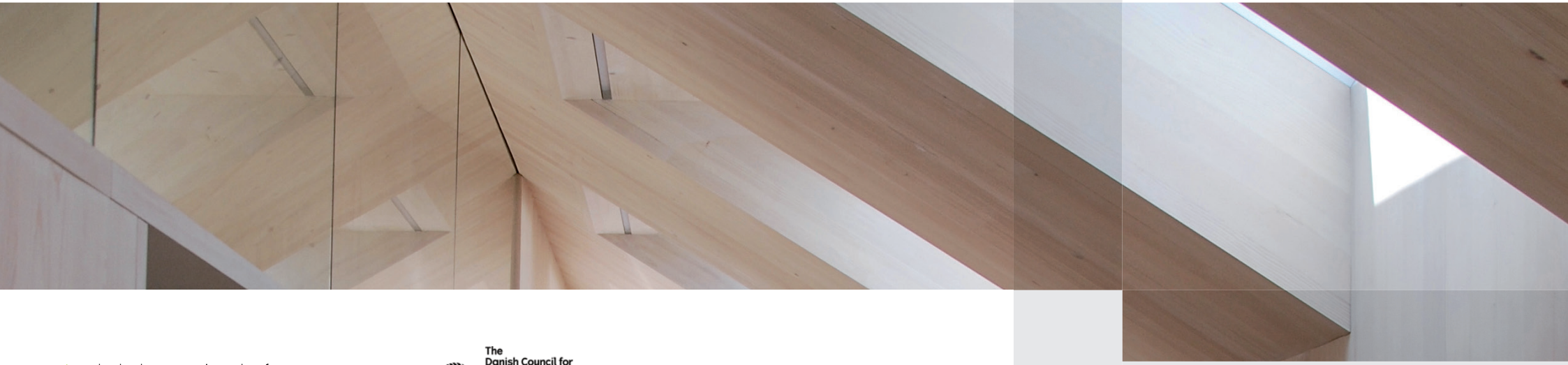
DESIGN PRINCIPLES AND BUILT EXAMPLES

For detached houses



strategic research centre for
ZERO ENERGY BUILDINGS

The
Danish Council for
Strategic Research

TITLE	Zero Energy Buildings - Design Principles and Built Examples for Detached Houses
EDITION	First edition
PUBLICATION YEAR	2014
AUTHORS	Anne Kirkegaard Bejder, Mary-Ann Knudstrup, Rasmus Lund Jensen, Ivan Katic
EDITORS	Mary-Ann Knudstrup and Anne Kirkegaard Bejder
LANGUAGE	English
NUMBER OF PAGES	60
LIST OF REFERENCES	Pages 56 to 58
ISBN	978-87-563-1603-3
ILLUSTRATIONS	Anne Kirkegaard Bejder, unless other information is given. List on page 59.
PHOTOS	List on page 59
LAYOUT	Louise Kragelund, Novagraf Ltd
PRINT	Novagraf Ltd
PUBLISHER	SBI forlag 15, A. C. Meyers Vænge DK-2450 Copenhagen SW Email sbi@sbi.aau.dk www.sbi.dk

Layout and printing of this publication was facilitated by the ALECTIA Prize 2010, awarded to the Strategic Research Centre for Zero Energy Buildings by the ALECTIA Foundation.

ACKNOWLEDGEMENT

Thanks to researchers and PhD students of the research centre whose knowledge of zero energy buildings (ZEB) has contributed to this publication. Their full contributions are available at www.zeb.aau.dk.

Thanks to the Advisory Board of the Centre, to Gudrun Schack Østergaard from Friis & Moltke, Claus Topp from NIRAS, Ditte M. Jørgensen from the Danish Technological Institute, Lind & Risør Ltd., HHM Ltd., Karsten Duer from VELUX and Carsten Pedersen from The Danish Construction Association for their input and comments.

The publication was produced by the Danish Strategic Research Centre for Zero Energy Buildings (www.zeb.aau.dk). The centre is a cooperation of research institutions and private enterprises. Among the research activities are 17 PhD projects. The Research Centre was established with support from the Danish Council for Strategic Research, the Programme Commission on Renewable energy and Environment.

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PREFACE

This booklet is one in a series published by the Danish Strategic Research Centre for Zero Energy Buildings:

- Zero Energy Buildings
  - Definition and future role in society
- Zero Energy Buildings
  - Design Principles and Built Examples for Detached Houses
- Zero Energy Buildings
  - Technical solutions

These booklets convey the research of the Centre regarding sustainable buildings to practice. The publication at hand includes own research, knowledge generated by the researchers of the Centre, and refers to results produced by the PhD students of the Centre.

This booklet is part of the Centre's work package 1, focusing on the development of zero energy buildings (ZEB) at concept level. As part of the work package a postdoctoral project has gathered new knowledge regarding ZEBs with the aim to clarify and articulate technical and architectural challenges associated with the development of holistic ZEBs, as well as challenges related to user behavior.

The booklet is directed primarily towards practicing architects and engineers. Moreover, the booklet may also provide interested users and professional and private developers and building owners an overall insight into various aspects of ZEBs, and hereby facilitate dialogue and form the basis of cooperation between users/owners and consultative parties.

Mary-Ann Knudstrup, Editor, Professor at Aalborg University
Anne Kirkegaard Bejder, Editor, Postdoc, Aalborg University
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Designing a zero energy building is a complicated task, and in order to achieve good results it is necessary to include knowledge from a range of sources. Therefore, cooperation is required between different professions and between generalists and specialists from the very beginning of the process. The purpose of this booklet is to support the integrated design process and co-operation between different professions. The subject areas are therefore 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 acquired, depending on the project in question.

Through a cross-disciplinary approach to architecture and building design, and based on an integrated design process, this publication will:

- introduce a number of design strategies and technologies which are particularly important for the development of zero energy houses. These strategies and technologies are illustrated through simple design principles and built examples

- identify technical and architectural potentials and challenges related to design strategies of crucial importance to the development of zero energy houses

- identify technical and architectural potentials and challenges related to the application of new technologies

- make visible engineering and architectural issues and create greater transparency, providing a point of departure for cross-disciplinary cooperation.

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INTRODUCTION

INTRODUCTION

The Danish government's target to make Denmark independent of fossil fuels by 2050 (the Danish Climate Policy Plan 2013) calls for considerable energy efficiency and an increase in the production of renewable energy. The building sector accounts for approx. 40 % of Denmark's total energy consumption (the Government 2009), and improvements in the energy efficiency of buildings is therefore crucial.

The development of integrated building concepts is an important contribution to this. These buildings should be designed with a very low energy demand, using renewable energy sources as compensation for energy from fossil fuels. Today, in order to reach energy neutrality, renewable energy must be produced on the building and/or on-site, or a share in the centralised production of renewable energy may be purchased. The conditions to be met for a building to be CO_2 neutral will change over time as collective energy supply will increasingly be based on renewable energy sources (Fig. 1). Likewise, local conditions of individual houses (such as local supply options, location and topography of the site, solar, shade and wind conditions as well as user needs and behaviour) will differ from one project to another. These variables are important for the performance of the zero energy building, and each project must therefore be designed on the basis of its own specific conditions and/or with a view to possible adaption options.

This booklet is a part of the work carried out by the Danish Strategic Research Centre for Zero Energy Buildings and describes the development of Zero Energy Building concepts – in this case detached houses.

ZERO ENERGY BUILDINGS

The Danish Strategic Research Centre for Zero Energy Buildings bases its activities on the following definition of zero energy buildings:

EXPECTED FUTURE DEVELOPMENT IN ZERO ENERGY BUILDING

Zero Energy Buildings are always designed with a very low energy demand

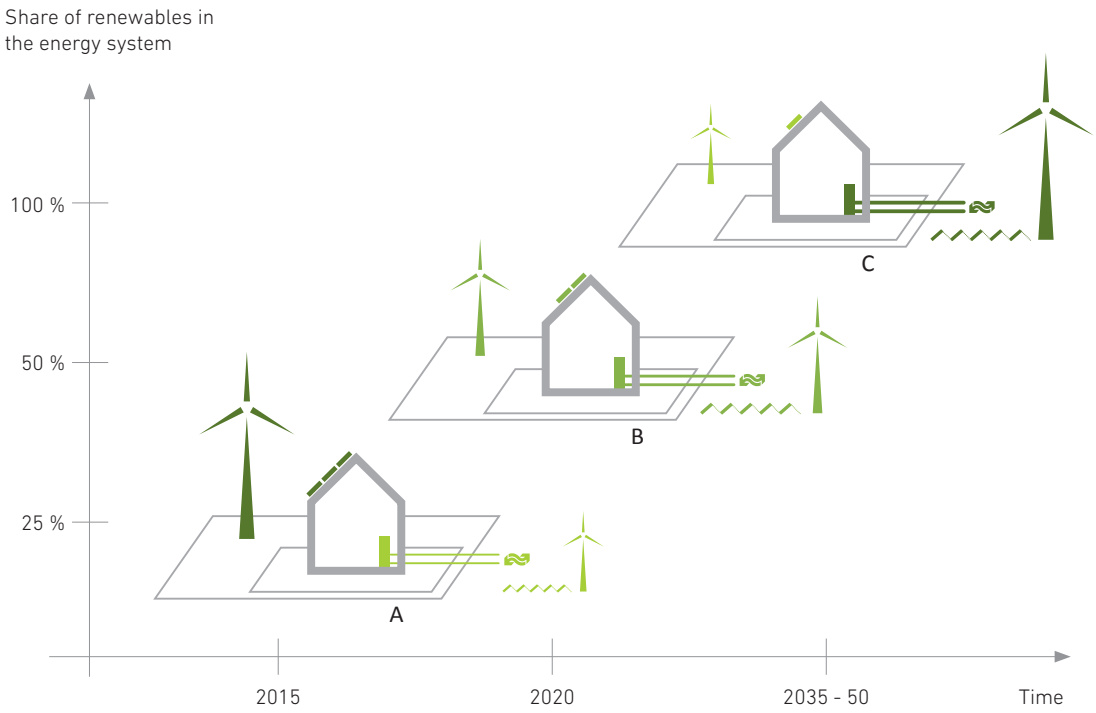


Fig. 1

A In 2015, the amount of renewable energy implemented in the energy supply system is limited. A Zero Energy Building is achieved through integration of renewable energy production (heat and electricity) on the building and/or on the site.

B In 2020, the amount of renewable energy implemented in the energy supply system will be larger. A Zero Energy Building is achieved through integration of renewable energy production (heat and electricity) on the building and/or through production at community level.

C In 2035, it is expected that building energy demand can be covered by renewable energy production integrated in the energy supply system. This might be supplemented by local production on the building.

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. (Danish Strategic Research Centre for Zero Energy Buildings 2014).

A STRATEGIC APPROACH TO DESIGN

Designing a Zero Energy Building (ZEB) not only involves reducing the energy need of the house – or producing (renewable) energy which will cover the energy use of the house- hold. This is only one aspect. A building is sustainable to the extent that it offers the right setting to its users, i.e. good day- light conditions, spatial experiences, functionality, a pleasant indoor environment as regards light, air, temperatures and good acoustics; in addition, it should grow old gracefully. When designing ZEBs for the future, it is therefore important that we focus on holistic solutions in which architecture, comfort, indoor environment and energy go hand in hand – if not, the buildings will not be sustainable in the long run.

The point of departure is to design the zero energy house with a very low energy demand through the building design (e.g. with a highly insulated and airtight building envelope, efficient low-energy windows, layout and proportions of rooms, choice of materials etc.). The house is designed with emphasis on high architectural quality, including good daylight conditions, exploitation of passive solar heat and natural ventilation, alternating between a focus on details and on the building as a whole. Energy demands are further reduced through the design of the building's technical systems. The energy demand of the building is covered by energy producing systems selected and designed for the specific building on the basis of available supply systems (Fig. 2).

READER'S GUIDE

This booklet is intended as a reference work, not a process guide, and is organised around different design strategies and technologies which are particularly important to consider in the development of new zero energy houses. In order to ensure consistency throughout the booklet, the elements below are used in the description of different design strategies and technologies; the general layout of the elements is illustrated in Fig. 3.

1. ASPECTS IN PLAY

Illustrates the aspects in play when working with a specific design strategy/technology, and the means which may be applied in order to accommodate both qualitative and quantitative aspects.

2. FOCUS POINTS

Indicates points which are important to consider regarding the specific strategy/technology.

3. DESIGN PRINCIPLES

Simple design principles illustrate different possible solutions related to the design strategies/technologies and outline focus points related to the specific solutions.

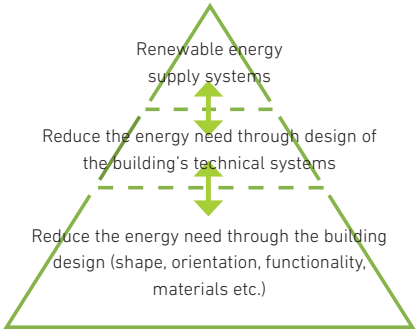


Fig. 2. Overall strategy for designing ZEBs.

4. BUILT EXAMPLES

Examples of the integration of a design strategy/technology.

5. HAVE YOU CONSIDERED...

The main section is concluded by a fact box briefly summarising the most essential points to consider.

6. PROCESS

Indicates at what point knowledge of the specific design strategy/technology should be included in the process – and when final decisions should be made (point of no return).

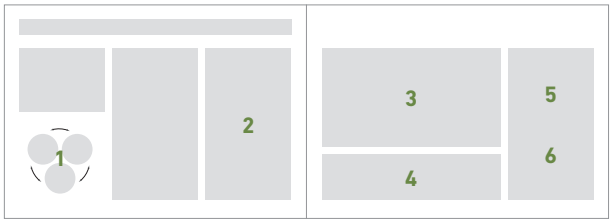


Fig. 3. Diagram of the overall layout of the reference work.

INTEGRATED DESIGN

Designing a building is a complicated process in which a large number of parameters are at play; in many cases the parameters are interconnected (Fig. 4). The complexity is further increased in the design of zero energy buildings (ZEB), in which a fine balance is required between the many design parameters if the building is to comply with the strict requirements regarding energy and indoor environment, without compromising on aspects of quality. Finding this balance requires an integrated design process in which input from engineers, designers and architects is continuously fed into the project.

Many versions of the "integrated design process" may be found, e.g. (Knudstrup 2004, 2010, Löhnert et al. 2003). In this case, it is not crucial which model is applied or what the individual phases are called. What is crucial is that from the very beginning of the process, a cross-disciplinary design team includes knowledge from several disciplines, e.g. design, engineering and architecture, and, depending on the project, knowledge from operating parties or other stakeholders. It is also essential that calculations and evaluations of the consequences of different design solutions on the technical performance of the building, as well as on users, architecture etc. are made continuously throughout the process. Coherence between degree of detail and project design stage is very important.

An essential element in this publication is to determine the stage in the design process at which considerations regarding design strategy/technologies should be included, and when in the process final decisions must be made (e.g. which energy system to use, how to integrate this, etc.). The identification of these points-of-no-return is crucial in order to avoid back-tracing or symptom treatment, as these are often destructive to both building performance and architectural coherence. In a simple and broadly applicable illustration of an integrated design process, we are operating in three overall phases, see Fig. 5.

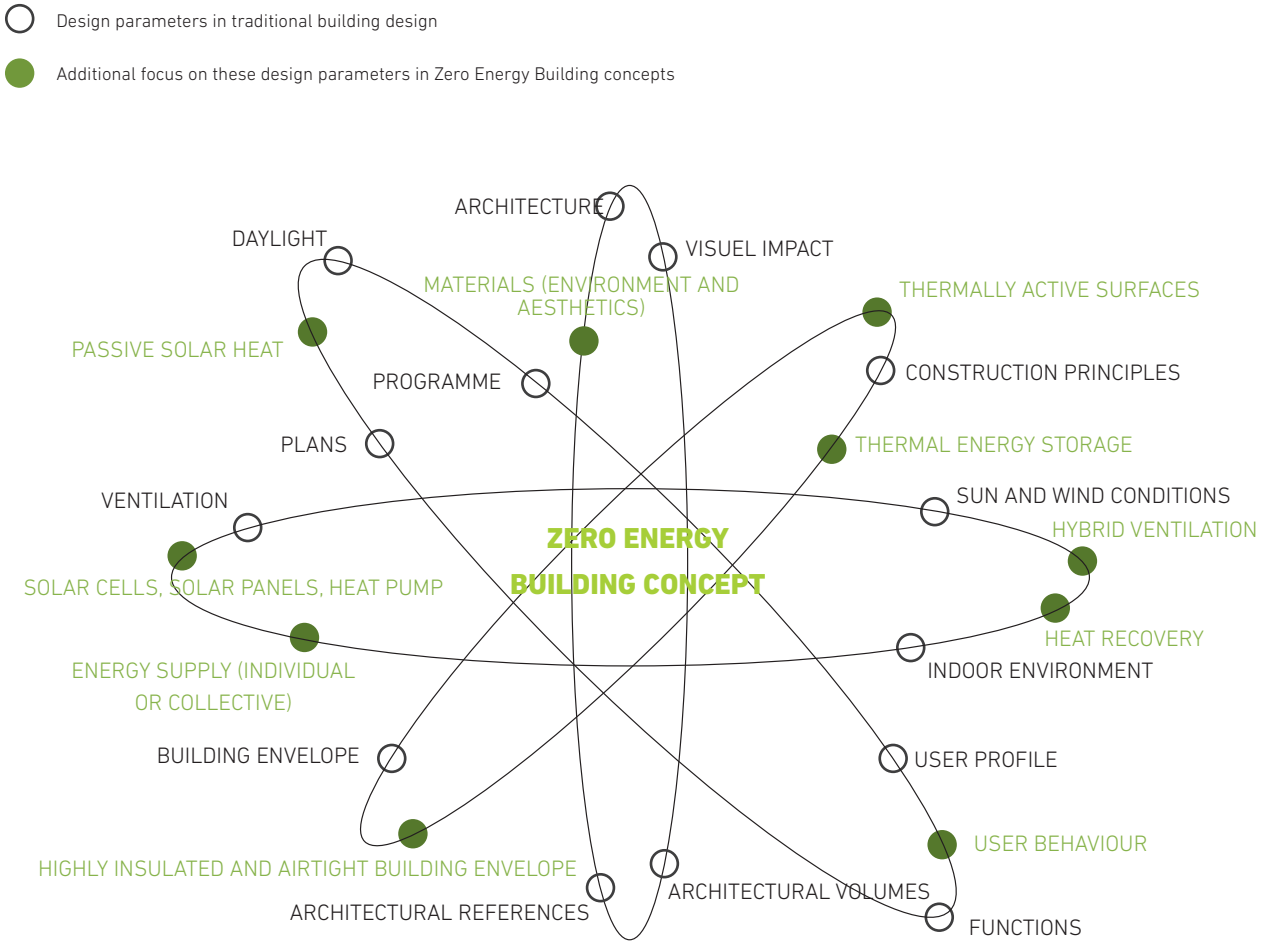


Fig. 4. Essential design parameters at play in an integrated design process. Diagram design based on (Knudstrup 2004).

This booklet seeks to clarify the importance of, and ideally promote, cross-disciplinary cooperation through an articulation of both architectural and engineering aspects and a clarification of when to include knowledge of the different disciplines in the design process.

However, the cross-disciplinary cooperation is often challenged by traditional working methods, differences in terminology and discourse and contractual issues (Knudstrup 2010, Petersen and Knudstrup 2013).

The three phases correspond to the first phases of a traditional design process up to and including the preliminary design, as regards project detail level, see Fig. 5.

This will be an iterative process in which knowledge acquired in the subsequent phases of the project may prompt a return to and adjustments of the early phases of the project. Consequently, the phases do not reflect a chronologically linear process, but rather relate to different stages in the development of the design.

The booklet is organised around the different design strategies and technologies, not the process. Throughout the booklet, Fig. 6 will illustrate when knowledge of the different design strategies/technologies is included in the process, based on the three phases. For instance, it may be essential to include knowledge of a specific technology at the early stage of defining the design criteria, whereas other knowledge of the same technology is not included till later in the process.

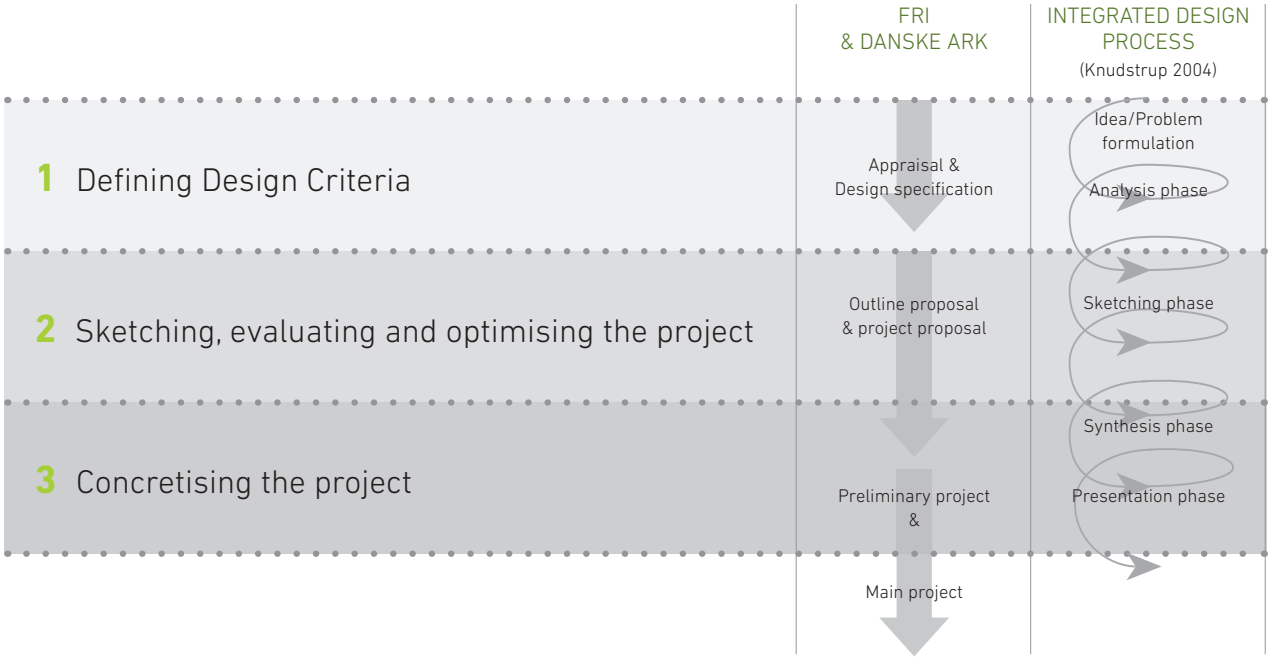


Fig. 5 Three overall phases of an integrated design process seen in relation to a traditional design process by FRI (the Danish Association of Consulting Engineers) & DANSKE ARK (The Danish Association of Architectural Firms) and the Integrated Design Process by (Knudstrup 2004).

Fig. 6 Illustrates the three overall phases of an integrated design process.

FRAMEWORK
BUILDING & CONTEXT

CREATING AN OVERVIEW OF THE FRAMEWORK OF A PROJECT IN ITS INITIAL PHASES CONSTITUTES AN ESSENTIAL DESIGN STRATEGY IN THE DEVELOPMENT OF A ZERO ENERGY HOUSE. THIS WILL CLARIFY THE CONDITIONS RELATED TO FOR INSTANCE LOCATION, MICROCLIMATE, AVAILABLE ENERGY SOURCES, STAKEHOLDERS' NEEDS AND REQUIREMENTS IN TERMS OF COMFORT AND ENERGY.

FRAMEWORK OVERVIEW

In order to achieve a holistic zero energy house, it is essential that the framework of the project is established at the beginning of the design process.

A house is not an autonomous entity but rather a dynamic day-to-day co-player in the residents' physical and psychological settings. It interacts with the surrounding architecture, functions, vegetation, infrastructural network, supply network, inhabitants and users of the area. Its outdoor spaces, secondary on-site buildings and vegetation form a transition between the private sphere of the building to the public sphere. Neighbouring buildings, vegetation and site topography will influence how the building is affected by daylight and shade, the opportunities for shelter from the wind etc. Likewise, the house interacts with its residents. It is not sufficient that the house is energy efficient; it should also support energy saving practices in order to function as intended after the user has moved in, and in a manner which is supportive of the well-being of the user. This requires an overview of the needs of the user as well as attention to the way in which these needs may/will develop overtime. Additionally, a plan should be developed for how the user may best prepare to live in a zero energy house. An overview of the framework is therefore an essential strategy when designing a zero energy house.

Examples of important parameters which should be identified:

- Requirements and wishes of the project stakeholders, including the owner and user
- Plans for the area (town and district plans, including framework provisions etc.)
- Character of the area (urban or rural)
- Infrastructure (traffic and energy)
- Architecture and materials in the area
- Access conditions to the site
- Vegetation
- Views (and risk of visual exposure)
- Architectural wishes (expression, functions, materials, atmosphere etc.)
- Requirements to the energy demand of the building
- Requirements to the indoor environment of the building, including daylight conditions

Identification of the above parameters will lead to a number of concrete design criteria which constitute the overall framework of the project.

The design criteria will be of both a qualitative and a quantitative character, and it is important that a cross-disciplinary design team identifies them jointly. Identifying the design criteria will lead to more transparency between the overall conditions under which the different professions are operating – and, consequently, to better insight into and understanding of the challenges characterising the working process of the entire design team.

It is important that the different design proposals are evaluated and optimized throughout the design process in relation to the established design criteria. Sometimes some of the design criteria must be re-evaluated or adjusted during the process. In those instances it is important that any changes are made visible for everyone in the design team, in order to keep the common goal clear for everyone. Having a clear overview of the frames of the project from the start of the process can minimize the risk of going down the wrong path and therefore help a more efficient design process along.

In the following, some of the parameters which are particularly important in the design of zero energy houses will be explored.

AVAILABLE ENERGY SOURCES

When designing a zero energy house, different issues must be considered regarding the possibilities of energy supply, e.g. the location of the site and the intentions of the owner.

It may be beneficial to create an overview of the energy supply options before the sketching of design proposals begins, as choice of energy supply may be decisive for the design of the building. Typically, collective energy supply will not affect the building design very much, whereas the utilisation of solar energy, for instance, will place great demands on the overall geometry of the building (i.e. roof surfaces or the incline, orientation and area of the façade); as well as demands on the placement of the building on the site with regard to shade from other buildings, vegetation etc. (see the chapter on Solar Panels and Solar Cells). The choice of energy supply will depend of a number of conditions (a selection is shown in Fig. 8) and must therefore be determined in dialogue with the owner of the building. In addition, connection to the collective heat supply system may be mandatory, and specific framework regulations may apply for the use/ prohibition of for instance solar cells or solar panels.

The most reliable price assurance is achieved by bringing down the energy need of the building through design, as subsidy schemes are politically determined and collective energy supply will be characterised by fluctuating energy prices. The production of energy on the building for own consumption may be a safe choice in terms of energy price, but includes high construction costs. Moreover, it will greatly influence the building design and will require maintenance. (Marszal 2012).

COLLCTIVE ENERGY SUPPLY

From a socio-economic point of view as regards a future fossil free Denmark, the zero energy house should be connected to the collective heat supply grid if possible, and if not, should use an individual heat pump (Lund 2010) (Fig. 7). More information on district heating and zero energy buildings is available in (Nielsen 2014). The zero energy house is always connected to the collective electricity supply grid in order to avoid local electricity storage, and to achieve energy security.

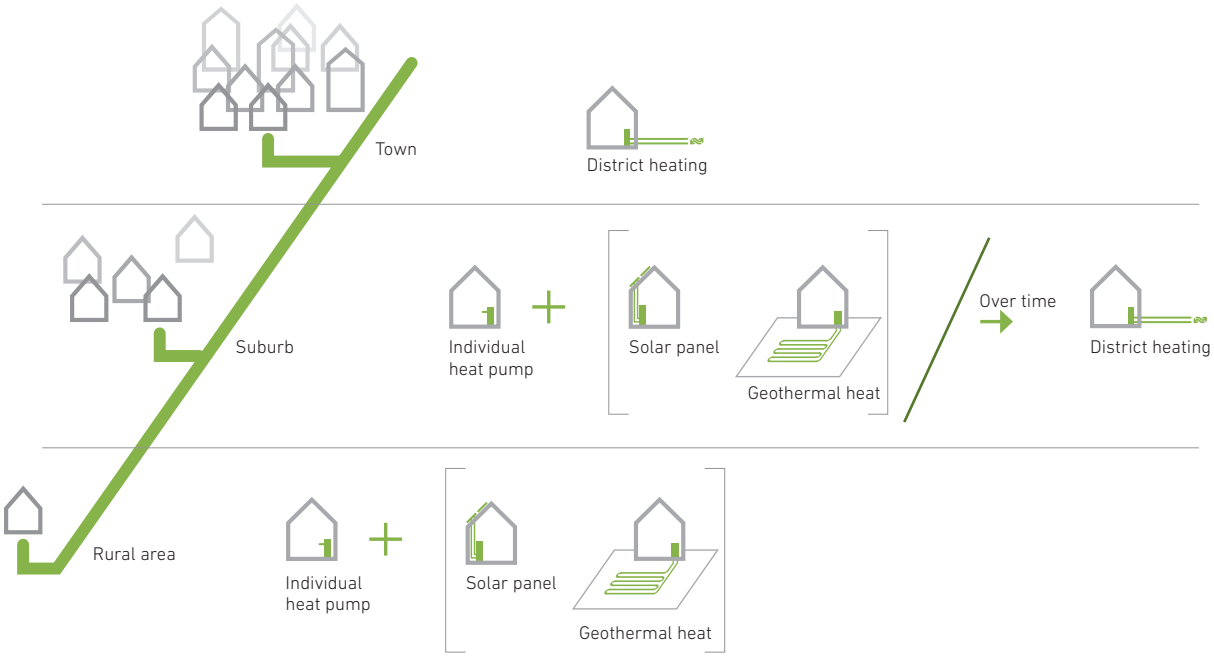


Fig. 7. New zero energy buildings within district heating areas should be connected to the collective supply system where possible. In areas without district heating, an individual heat pump is recommended for heat supply. If plans exist for future connection to district heating, the internal heating system in the building should be compatible with the district heating supply system.

LOCAL PRODUCTION

For a zero energy house, energy production counterbalancing energy use is also necessary. The location of energy production will depend on different conditions (see, i.a., Fig. 8), and sale to the grid is politically determined (check the rules in force).

	Degree of price assurance	Influence on building design	Maintenance	Degree of "ownership"
On the building	High/low*	Large	Owner's responsibility	High
Houseowners' association or equivalent	High/low*	None	Responsibility of owners' association	High
Collective energy supply	Relatively steadily rising prices	None	None	Low

Fig. 8. Location of energy production. *A high degree of price assurance in small systems with little or no export. A low degree of price assurance in large systems with much export to the grid.

THE USER

The user composition is decisive for the programming of the house and its spatial organisation as well as for the design and dimensioning of the technical systems of the building. At the same time, user behaviour will have an impact on the extent to which expectations to energy use, indoor environment and comfort will be met after the commissioning of the building.

SIGNIFICANCE OF USER COMPOSITION

The composition of the household will have an impact on the way in which the building is used and, hence, on its functionality. Which rooms will the household need? What is the need for interaction between rooms, and what is the need for daylight (amount and quality) in the individual rooms? Good daylight conditions in all rooms and spatialities which may house different functions can help to ensure the functionality of the building over time.

The number of people in the household has become relatively more important to the heat demand as building envelope standards have improved. This is due to the fact that the heat demand has been reduced to a point at which the heat (energy) supplied to the room by the people in it will be of greater significance for the overall energy balance (Fig. 9). In 2010, energy use for electricity constituted a significantly larger portion of the total energy use compared to the energy use for hot water. Envisaging a reduction in the electricity use of households of 50% in 2050 compared to the 2008 level (Mathiesen et al. 2009), this balance will be levelled out significantly, and heat contributions from appliances will be reduced (Fig. 10).

In the majority of cases, the user composition will change over time. For instance, several single-family house owners live in their houses over a lifespan. It is therefore important to design a robust and flexible house, both in terms of functionality and technology, so as to accommodate for changes in the needs of the household as well as variations in load.

The three most common household compositions in single-family houses and farmhouses in Denmark are couples without children, couples with one or two children, and singles without children (Fig. 11)

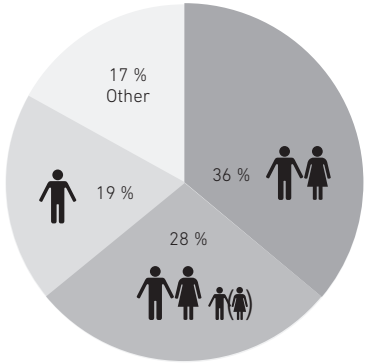


Fig. 11. The most common household compositions in single-family houses and farmhouses in Denmark (data from: Agerskov and Bisgaard 2012).

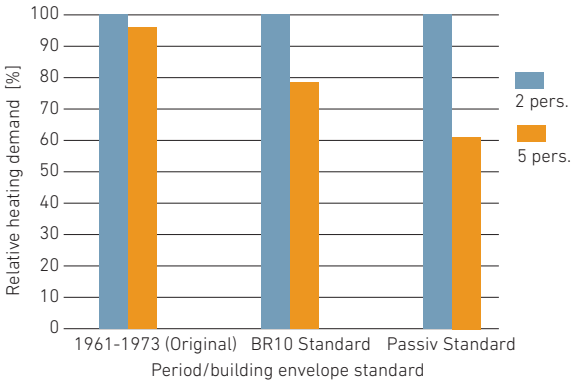
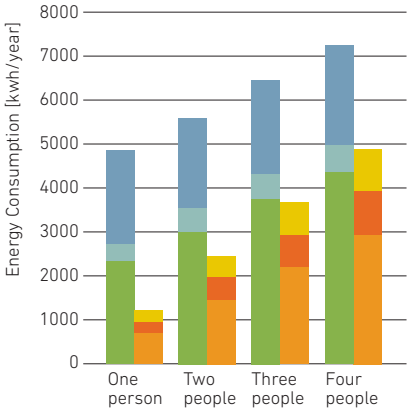


Fig. 9: Relative heating demand at different building envelope levels for houses with two and five and constant electricity use (Jensen et al. 2011).

Electricity use and hot water consumption in 2010



Electricity use (reduced by 50% according to the Climate Commission) and use of hot water in 2050

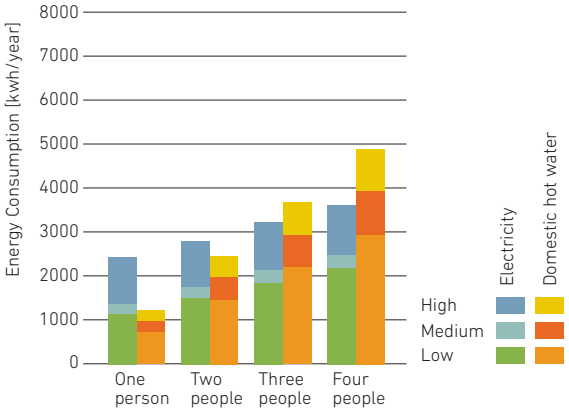


Fig. 10: Examples of the correlation between household compositions and the derived differing needs to be accommodated by the robustness of the building.

FOCUS POINTS:

- Accommodation of non-standard needs (e.g. other temperatures or extra airing) in the house
- Possibility of overruling automatic systems
- Possibility of individual control of temperatures and air in each room. Some users prefer 22°C in the living room and 18°C in the bedroom
- Ensuring the interaction of the systems
- Possible service plan for the systems to ensure they will continue to function as desired
- User-friendly feedback.

USER BEHAVIOUR

Designing a house with optimal functionality is one thing, in theory. It is another when users move in and begin interacting with their house and its systems. The risk is that the users will be dissatisfied – either because the house does not accommodate their requirements of comfort, or because their actual energy demand exceeds that which was expected in the first place. It is therefore important to point out to the house owner/user the connection between their use of the house and the technical performance of the building. The calculated energy use and/or indoor environment, for instance, often presuppose automatic control of ventilation and solar shading. It is essential that the users understand the system, if they overrule the automatic control. Otherwise the consequence may be an increase in energy use, poor air quality and excessive temperatures.

THE USER AND THE INTELLIGENT HOUSE

An increasing amount of technology tends to be entering our houses. Therefore, it is important that the building and its technologies are designed in a way that the users can apply them, so that the building and its systems will interact at an optimal level with the user, and the user does not feel a loss of control. One way to make consumption and control of the indoor environment visible to the user is to install easily accessible user-friendly displays in the house, or apps for mobile units.

In the project "Intelligente energiydelser i lavenergiboliger baseret på brugerdreven innovation" [Intelligent energy services in low energy buildings based on user-operated innovation], (Jørgensen et al. 2012), under the auspices of the Danish Technological Institute, an energy-optimised system to control indoor environment and energy (heat, ventilation, window openings and solar shading) was developed for the inhabitants of the demonstration project EnergyFlexHouse. In addition, a tablet app was developed, enabling the inhabitants to override the automatic control. The project concludes that the automatic control in a given winter period will result in a 30% lower space heating demand, compared to a situation where the test family themselves controlled the systems from the tablet. The family found that the automatic control system that had been developed was definitely an acceptable solution with regard to indoor environment, particularly when the consequences were made visible to them. (Jørgensen et al. 2012).

When designing control and visualisation tools, attention should be paid to the following:

- Control and visualisation panels must be user-friendly. It should be easy to change settings, and to reset them to the most energy efficient setting (Hauge 2011, Entwistle 2011).
- The consequences of changes to the standard settings for the energy use should be illustrated (Jørgensen et al. 2012), for instance in tables showing energy use and possibly extra costs when increasing temperatures by one or two degrees.
- Indoor environment and comfort parameters should be illustrated in a simple way so as not to confuse the user, i.e. by a happy/unhappy smiley, as done by the Danish Frederikshavn housing association (Madsen 2013).
- In order to reduce energy use and ensure a satisfactory indoor environment, it is important that control parameters (e.g. solar shading, heat, mechanical and natural ventilation) are connected in the correct order in the control algorithm in relation to the weather conditions (Jørgensen et al. 2012).

Another research project studying the user experience in three VELUX Model House 2020 demonstration projects concludes, among other things, that users soon learn to manage control panels and generally accept the automatic control. The visualisation panels may also have a motivating effect, as they display the correlation between energy, indoor environment and user behaviour (Olesen, GGH 2014).

RENOVATION

In energy renovation of houses it is similarly important to involve the users. A study based on qualitative interviews of house owners and other actors in energy renovation projects (Vlasova and Gram-Hanssen 2014) and studies based on more quantitative data (Gram-Hanssen 2014) demonstrate that it is not only a question of the energy efficiency of the house, but also whether the house will support energy saving practices after renovation. These studies suggest that in renovation work, it could be beneficial to consider the following:

- Include the users in the decision-making process and in the choice of technological solutions; this will increase the likelihood that the building technologies chosen will be understandable to the user and will be managed so as to reduce consumption.
- A reduction in consumption can be achieved by the installation of efficient technologies, but also by making it easy and more attractive to the user to consume less energy, e.g. by establishing an attractive laundry-drying space, choosing appliances which are easy to control and by turning off stand-by settings.
- Users often prefer larger houses and for instance more bathrooms as part of the renovation, which results in higher consumption irrespective of energy efficiency measures taken. It is therefore important to make the consequences of their different choices visible to the users.

THE MICROCLIMATE

In the preliminary phases, qualities and challenges related to the microclimate will be identified. This is essential for the design of the zero energy house, both in order to ensure a well-integrated building in its local context, and to make optimal use of passive means such as sun and wind.

Due to the highly insulated building envelope and the low heating demand, there is no longer the same need of passive solar heat (Fig. 17) (Jensen & Petersen 2013). An important aspect in the development of zero energy houses is therefore to reach a balance which will ensure the best possible daylight conditions (amount and quality) and at the same time minimise the risk of overheating caused by passive solar heat.

Working with daylight and passive solar heat presupposes awareness of the position of the sun in the sky during daylight hours and during different seasons (Figures 12 to 14) and any shade conditions on the site (Fig. 15). This knowledge is used when positioning the building on the site, and when designing the building and deciding about the placement of functions, day- light conditions and utilisation of/limitations to passive solar heat according to the needs.

In order to design for wind shelter conditions and natural ventilation it is important to gain knowledge of local wind conditions around the house. It may make a great difference whether a house is built in a well-established residential area or in a newly developed open site in which it may take years for vegetation to be established. This may affect wind conditions around the house, and the user may feel bothered by visual exposure to neighbours etc. (Brunsgaard et. al 2012). It may therefore be advantageous to pay attention to (expected) changes in the microclimate on the site and take this into account when designing the building, e.g. in the form of solar shading and wind protection.

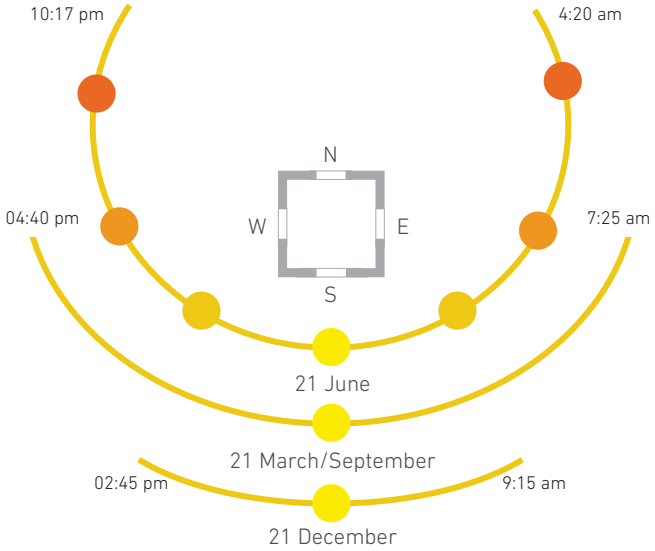


Fig. 12. The horisontal movement of the sun at summer solstice, winter solstice and equinox, respectively.

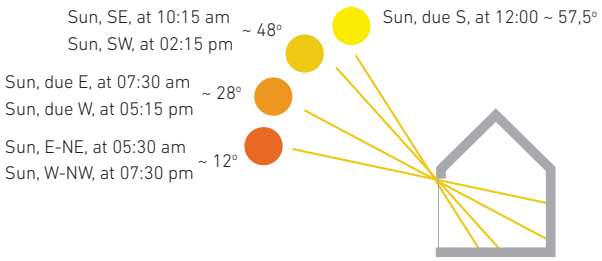


Fig. 13. The vertical movements of the sun across the day at summer solstice, 21 June.

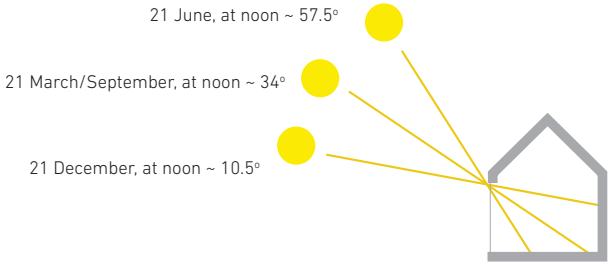


Fig. 14. Sun angle at noon at summer solstice, winter solstice and equinox, respectively.

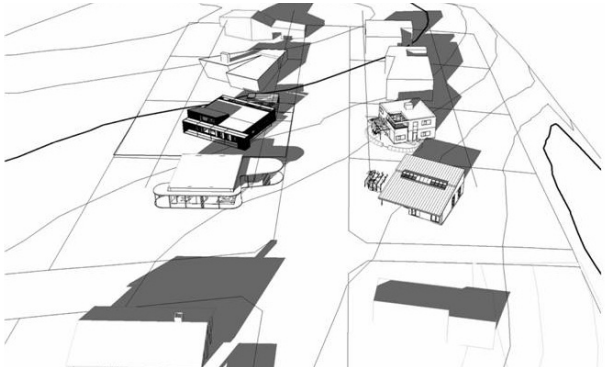


Fig. 15. This illustration from the Comfort Houses in Denmark shows the importance of taking into account shade conditions caused by neighbouring sites. This problem is particularly prevalent at winter solstice. Illustration by Bjerg Architecture Ltd.

FOCUS POINTS

- On-site sun conditions
- Shade from surrounding buildings and vegetation (Fig. 16)
- On-site wind conditions
- Topography
- District plans stipulating building zones may cause problems in utilising passive solar heat, daylight and views, due to neighbouring buildings.

Consideration of the above will identify the possibilities of:

- Orientation of the building
- Daylight (the path of the sun over the day/year)
- Need of solar shading
- Natural ventilation
- Outdoor spaces with sunlight and shelter
- Possible utilisation of solar energy (solar cells and solar panels).

Fig. 16. Neighbouring buildings and vegetation may have a large impact on daylight in the house, and on the utilisation of and/or limitations to passive solar heat.

THE NEED OF PASSIVE SOLAR HEAT

Typically, the utilisation of solar energy for the heating of the building has been an important element in the design of low-energy buildings. The use of passive solar heat is still an important strategy when designing a zero energy house, but due to the highly insulated building envelope and the resulting low energy demand, the need for passive solar heat is no longer as prevalent. A simplified calculation provides an idea of the need for passive solar heat (Fig. 17).

A cold winter's day, the sun is shining and two people are at home in a single family house of 150m^2 built according to Building Class 2020

Heat loss (15W/m^2 x 150m^2)	2250 W
Heat load from two people, 100 W each (~89% of Be10 value)	200 W
Heat load from appliances (~76% of Be10 value)	400 W
Heat demand to be covered (150m^2 x 15 W/m^2 – 600 W)	1650 W
Solar heat contribution (towards the south) g-value (triple glazing) 0.55, glazing proportion of window 0.75, no shading	~700 W/m^2
Necessary window area (1650 W / (700 W/m^2 x 0.55 x 0.75))	= 5.7m^2

Consequently, the window area should be designed on the basis of:

- Daylight (amount and quality)
- Possibly a larger area, e.g. to provide a view or contact to outside
- An investigation of the need for solar shading

Fig. 17. A simplified calculation provides an idea of the need for passive solar heat.

COMFORT AND **INDOOR ENVIRONMENT**

Comfort in zero energy houses is about the user's physical and psychological well-being. Issues of comfort in the house range from the sensuous perception of space, materials, relation to surroundings etc. to the measurable indoor environment; i.e. temperature, air quality, acoustics and light. A study demonstrates that improvements in comfort, functionality and indoor environment of a single-family house may motivate its owners to carry out energy renovation (Mortensen 2014). Ensuring comfort and a favourable indoor environment are therefore crucial in the design of new zero energy houses.

As a minimum, the building must meet the requirements of the current building regulations. The zero energy house is, however, characterised by its favourable indoor environment, thus it is recommended to aim for the best possible conditions at the lowest possible energy use; improving the indoor environment does not necessarily require extra energy. E.g. by using natural ventilation it is possible to increase air exchange during summer months without a resulting increase in energy use. The Building Regulations stipulate very few specific requirements regarding the indoor environment of single family houses; a basis of some requirements is listed in Fig. 18. It is thus essential that in the initial phases, the cross-disciplinary design team together with the users/house owners clarify wishes and requirements for the comfort and indoor environment, but it may also be worthwhile to formulate some qualitative aspects.

Thermal:	20 to 26°C, with possible temperature reduction in bedrooms
Atmospheric:	CO_2: 800 ppm above outdoor concentration RH 25 to 60 %
Visual:	Daylight factor minimum 3 %
Acoustic:	Reverberation time 0.5 Noise from installations L Aeq,T : • Living rooms <32 dB(A) • Bedrooms <26 dB(A)

Fig. 18. Examples of requirements (Olesen, B et al. 2013, DS/EN15251)

QUALITATIVE DESIGN CRITERIA

The research project studying the user experience of three VELUX Model House 2020 demonstration projects indicates that users experience a positive relationship between daylight, air quality and natural ventilation and observe improvements in well-being as a result hereof (Olesen, G. 2014).

Design criteria may include:

- User co-determination as regards management of systems in the house (temperatures, air quality and daylight)
- Independent control of various zones/functions
- Visual character and tactility of materials
- Need for daylight according to the use of the house
- Need of artificial lighting (e.g. amount, quality, atmosphere etc.)
- Needs related to the functionality of the house (functions, relations between rooms and to outdoor spaces etc.) (Fig. 18)
- Views and contact to surroundings, while avoiding visual exposure

Fig 19. A highly insulated and airtight building envelope minimises downdraft and draft, and comfort may be achieved, even close to large window areas.

QUANTITATIVE DESIGN CRITERIA

THERMAL INDOOR ENVIRONMENT

In zero energy houses, there should be no problems regarding downdraft and cold surfaces. Due to the very low heat demand, the temperature will increase rapidly when windows are exposed to direct sunlight, and compliance with excess temperature regulations should be verified. Design criteria may include:

- Protection against excess temperatures and large variations in temperature during day and night
- Maximum excess temperatures: >26°C max. 100 hours per year, > 27°C max. 25 hours per year
- Possibly consider whether it is necessary to distinguish clearly between winter and summer clothes – as in office buildings – as the adaption of clothing may result in thermal comfort within a larger temperature interval.

ATMOSPHERIC INDOOR ENVIRONMENT

For zero energy houses choice of ventilation rate and control strategy are crucial as a large part of the building's energy demand relates to ventilation. Design criteria may include:

- Minimum requirements for ventilation rate are stipulated in the Danish Building Regulations
- Air quality in individual rooms. Often, only the average air quality is ensured, which may result in good air quality in some rooms, but not in others. The indoor air quality in a room may depend on whether it is used as a children's bedroom (one child) or as the master bedroom (two adults)
- Possibly consider demand-controlled ventilation for the optimal air quality in proportion to energy use
- Relative humidity in the house. In Denmark, for many years, focus has been on minimising the relative air humidity in houses in order to avoid mould etc. A study demonstrates, however, that houses with a high exchange of air may become too dry during the winter period (Larsen et al. 2012) Humidity conditions should therefore be tested.

ENERGY AND ENVIRONMENTAL PROFILE

VISUAL INDOOR ENVIRONMENT

The visual indoor environment includes both daylight and artificial light. Design criteria may include:

- Sufficient glazing area,correctly located with regard to orientation and height to ensure good daylight conditions (see DF in Fig.18)
- Option of direct sunlight during the winter period to counteract winter depression (see Fig. 18)
- Daylight relates to both amount and quality, e.g. the quality of the light as regards colours and texture after it has passed through the window pane, and the option of avoiding glare, large contrasts and reflection
- Artificial lighting should secure good light conditions for the different functions
- Requirements for energy efficient artificial lighting
- The interplay between daylight and artificial lighting.

ACOUSTIC INDOOR ENVIRONMENT

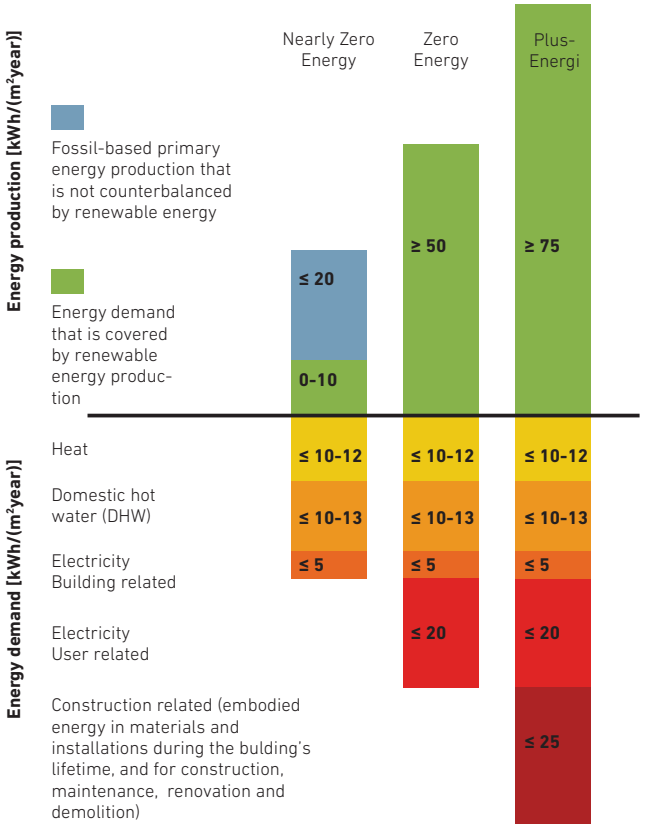
The acoustic indoor environment comprises both room acoustics and building acoustics. Design criteria may include:

- Room acoustics: requirements regarding reverberation time, e.g. by ensuring sufficient sound absorption. In many modern houses, surfaces primarily consist of glass and hard surfaces such as plasterboard walls and ceilings. Such rooms will have a long reverberation time and consequently poor room acoustics
- Building acoustics: requirements regarding sufficient muffling of sound which is considered to be noise. This applies to noise from the outside, noise between rooms and noise from installations
- For detached houses, focus will primarily be on noise from installations (e.g. ventilation) and noise between rooms.

Fig. 20: Energy balance ZEBs; Nearly Zero Energy, Zero Energy and PlusEnergy buildings. For the calculation of the energy balance of Nearly Zero Energy Buildings, different primary energy factors are used, dependent on the energy source. These factors may vary over time, and rules in force should be checked.

ENERGY

The target for the energy performance of zero energy houses is determined in consultation between advisers and house owner. On the basis of experiences from recent Danish and international research activities, the Danish ZEB research centre has set up the following energy targets for Nearly Zero Energy, Zero Energy and PlusEnergy Buildings:



ENVIRONMENTAL PROFILE

The interest in environmental certification of buildings has increased considerably, and is often a concrete requirement in competition briefs. In Denmark, the building industry has chosen DGNB as the sustainability certification system to be used, adapted to Danish conditions by Green Building Council Denmark. At present, a certification procedure exists for new office and commercial buildings, and procedures are currently being developed for other types of buildings. In the present certification procedure, the sustainability of the project is weighted on the basis of five overall parameters: environmental, economical, sociocultural & functional and technical qualities are weighted at 22.5% each, and process is weighted at 10% in the overall assessment. In addition, the site quality is weighted as a significant aspect. (Green Building Council Denmark 2014). Examples of assessment criteria appear from Fig. 21.

- ENVIRONMENTAL: e.g. LCA, Primary Energy Demand, Local Environmental Impact, Biodiversity and Interaction
- ECONOMIC: e.g. Building-related LCC, Suitability for Third Party Use
- SOCIOCULTURAL AND FUNCTIONAL: e.g. Indoor Environment (visual, air, thermal, acoustic), Efficient Use of Floor Area, User Influence on Building Operation, Quality of Outdoor Spaces
- TECHNICAL: e.g. Building Envelope Quality, Ease of Cleaning and Maintenance
- PROCESS: e.g. Integrated Planning, Comprehensive Project Definition, Sustainability Aspects in Tender Phase, Construction Quality Assurance
- SITE: e.g. Site Location Risks and Conditions, Access to Transportation and Specific-Use Facilities, Connections to Utilities

Fig. 21. Examples of assessment criteria in DGNB-DK, based on (Green Building Council Denmark 2014)

ENERGY EFFICIENT REFERENCES

It may be profitable to include architectural and technical references in the design team's preliminary meetings in order to establish a shared frame of reference.

Energy efficient references may range from entire projects, compositions, expressions, materials and details to well integrated technical solutions, systems etc. (Figs. 22 to 26).

A broad selection of projects is shown in the book Net Zero Energy Buildings – International projects of carbon neutrality in Buildings (Voss & Musall 2011) and at www.enob.info/en/net-zero-energy-buildings/map/.

Fig. 22. In the demonstration project EnergyFlexHouse at the Danish Technological Institute, indoor environment parameters and energy use are visualised for the user. The system is user controlled via computer apps.

Fig. 23. The EnergyFlexHouse at the Danish Technological Institute, is designed as a zero energy house. Solar cells and solar heating systems integrated in the roof produce the energy required to cover the energy need for indoor environment, hot water, artificial lighting, household and transportation by an electric car (Ravn & Grimmig 2011). Examples of other energy efficient means are open rooms lit from both sides, partially vaulted ceilings with opening skylight windows, which may increase natural ventilation on hot days.

Fig. 24.The architectural expression of energy efficient houses may vary considerably, as illustrated by the diversity of the Comfort Houses in Vejle, Denmark. Seen from above it is 43 Stenagervænget (ART Ltd and Rambøll Ltd), 28 Stenagervænget (Jordan+Steenberg and Cenergia Ltd), 39 Stenagervænget (Bjerg Architects Ltd and Erasmus & Partners Ltd).

Fig. 25. Solar shading is an important element in ZEB design. For the terraced houses Lærkehaven in Lystrup, Denmark (2008, Architect Herzog + partner) manual shutters on southern, eastern and western facades facilitate a balanced utilisation of passive solar heat. Other strategies applied in the project are highly insulating and airtight building envelope, heat accumulating ceiling panels with phase change materials, use of LED lighting and use of FSC certified wood (Boligforeningen Ringgården 2014).

Fig. 26. The comfort house at 45 Stenagervænget, Vejle, Denmark (Hundsbæk & Henriksen Ltd and Ravn Architecture), which was built as a passive house, has a glass-covered atrium as its focal point. The atrium is a source of daylight and by means of highly placed windows in the atrium and split-level floors, natural ventilation may be increased on hot days. Rooms lit from both sides, soundproof floor structure with acoustical surfaces and low-energy appliances are other applied strategies.

HAVE YOU CONSIDERED...

ABOUT THE FRAMEWORK OF THE BUILDING

- Local architecture, materials and legal frames?
- Sun and wind conditions on the site?
- Collective and/or individual energy supply – and will this influence the building design?
- User's need for functionality, space, materials, atmosphere, views, privacy etc.?
- Robustness and flexibility of the design with regard to changes in user composition and user needs?
- Which energy requirements must the building design meet?
- Which demands on indoor environment (daylight, temperatures, indoor air quality, acoustics) must be accommodated by the building design?
- To what extent should user behaviour, e.g. as regards the control of systems in the building, be taken into account?
- The use of displays or apps?

PROCESS

The framework of the project is defined during the first phase of the design process. Articulation and definition of project design criteria identify the joint target of the cross-disciplinary design team.

If the house must be DGNB certified, this should be determined from the very beginning of the design process as certain parameters then will in focus.

If the house must be DGNB certified, this should be determined from the very beginning of the design process as certain parameters will then be in focus.

BUILDING DESIGN PRINCIPLES

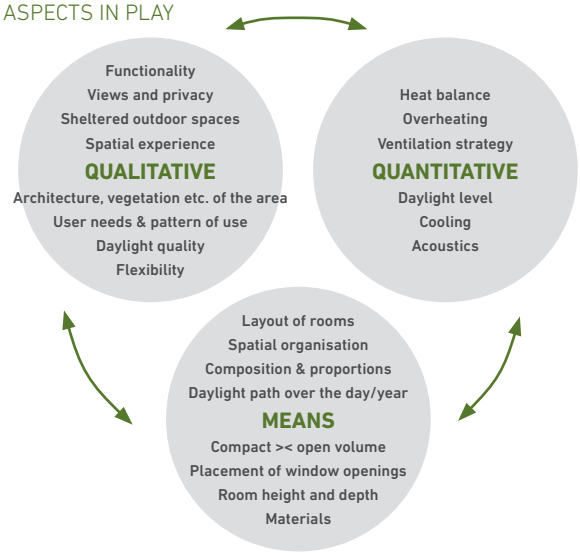
BUILDING SHAPE, FUNCTION, ORIENTATION, DAYLIGHT, MATERIALS AND VENTILATION ARE CENTRAL ASPECTS IN THE DEVELOPMENT OF HOLISTIC ZERO ENERGY BUILDING CONCEPTS. LARGE ENERGY SAVINGS ARE ACHIEVABLE IF THESE DESIGN PARAMETERS ARE TREATED STRATEGICALLY AND INCLUDED EARLY IN THE DESIGN PROCESS.

SPACE AND FUNCTION

In many respects, the overall building design is decisive in the development of the zero energy house. The house must constitute the framework of good life conditions, focusing on the physical and psychological well-being of its inhabitants; at the same time, the building design must accommodate zero energy requirements.

Through its building form, its functional layout and the proportioning of rooms, orientation, utilisation of daylight and choice of materials, the building will communicate with its users and surroundings. At the same time, the overall building design is essential for the technical performance of the building, e.g.; how much energy is required to heat the building, what is the need for artificial lighting and the possibilities (and effect) of natural ventilation? It is, therefore, essential to perform calculations of the building's performance throughout the design process, which can inform the design of the building.

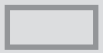
ASPECTS IN PLAY



The highly insulated and airtight building envelope of low energy buildings reduces the significance of compactness (Fig. 27). The need for heating is reduced, and the need for passive solar heating is similarly reduced. One problem that appears in some low energy buildings is related to the discomfort caused by over- heating; this is often the result of large glass sections towards south without effective solar shading or venting. A study by (Persson et al. 2006) shows that the size of energy efficient windows is not a major influence on the heat demand in winter, due to the insulation properties of the window panes; however, the size of the panes greatly affects the need for cooling in summer (when no solar shading is used). One could, therefore, benefit from making sure windows are more evenly oriented.

The above will pave the way for future zero energy houses to be designed on the basis of a holistic daylight strategy tailored to user needs and room functions, and for determining the geometry and orientation of the building on the site on the basis of not only compactness and passive heat gains, but also taking into account views, privacy, spatial experience, sheltered outdoor spaces etc.

L-shaped house, one storey, h = 3.5 m
Surface area = 498 m^2
Transmission loss ~ 1626 W



Rectangular house, one storey, h = 3.5 m
Surface area = 482 m^2
Transmission loss ~ 1586 W

Compact, 2 storeys, h = 6.3 m
Surface area = 368 m^2
Transmission loss ~ 1430 W

Fig. 27. Transmission loss for building typologies. Area 150m^2, glass area 30%, average U-value building envelope excl. windows = 0.11 W/m^2K, U-value windows = 0.8 W/m^2K. Calculated for a heating season Nov-March, average outdoor temperature of 1.2°C and indoor temperature of 22°C.

FOCUS POINTS

- Room needs of daylight, temperatures, views, access to outside etc.
- Room orientation, e.g. the path of the sun during the day
- Layout of rooms, spatial variation and relation between rooms
- The expression of the building
- Solar shading and venting
- Layout of installations
- Ducts and piping must be integrated in correlation with constructions and functions (e.g. see the section on Heating and the section on Ventilation).

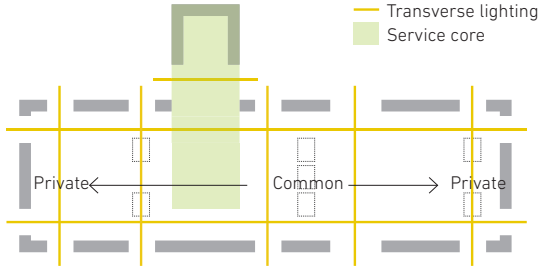
Moreover, it is important to include a certain degree of flexibility in the design of the house, taking into consideration the long lifespan of the house, changes in household composition and user needs.

Examples may be:

- Functional flexibility, in which spatial organisation and the design of individual rooms will accommodate changes in function
- Choice of construction/building system, including the lifespan of components, so that a distinction may be made in the construction process between permanent building elements (bearing constructions) and replaceable elements (e.g. non-bearing façade and walls).
- Easy accessibility with an eye to maintenance and replacement of installations (typically, the lifespan of technical installations is lower than that of building constructions, and new technologies are constantly being developed).

DESIGN PRINCIPLES

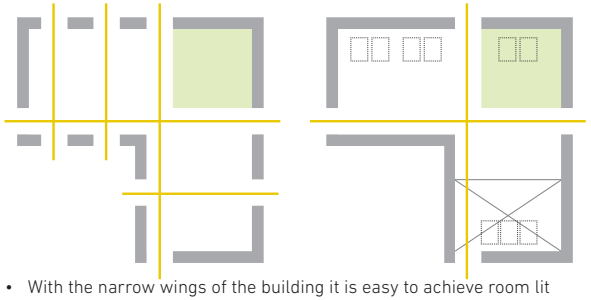
RECTANGULAR HOUSE



- The narrow body of the building combined with skylight provides good options for rooms to be lit from more than one side, which will secure a high daylight level, good light distribution in the rooms, possibility of perceiving the path of the sun over the day and direct sunlight, which will counteract winter depression
- Central service core minimises duct lengths, reducing energy consumption
- Light partition walls allow for a few large rooms or several small rooms, depending on the needs of the household
- Zoning, e.g. as regards temperature needs
- Rooms lit from two sides provide good possibilities for cross ventilation.
- See an example in Fig. 28.

Fig. 28. A built example of a rectangular house built according to the Passive House standard is this traditional Danish single-family house from Lind & Risør Ltd.

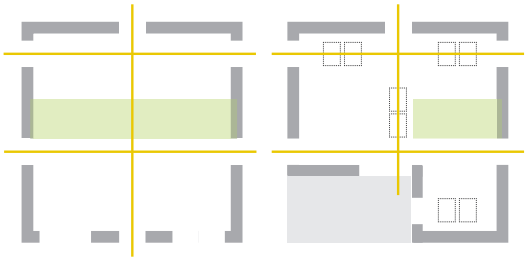
L-SHAPED HOUSE



- With the narrow wings of the building it is easy to achieve room lit from both sides. Transparent/translucent partitions and skylight will increase the daylight in rooms with only one façade
- Central service core minimises duct lengths
- The L-shape creates a sheltered outdoor space, and views across the outdoor space form a strong relation between indoor and outdoor as well as increase the sense of spatiality
- Double-height rooms will enhance natural ventilation, due to thermal buoyancy
- Bedrooms facing north or east and living rooms facing south and west will minimise cooling needs
- See an example in Fig. 29.

Fig. 29. A built example of an L-shaped house is Home for Life in Lystrup, Denmark, which is designed as a plus energy house.

COMPACT HOUSE



- Rooms lit from both sides may be achieved by means of transparent/translucent partition walls and skylight
- Central service core minimises duct lengths
- The compact body of the building results in a small surface area
- Two storeys may create differentiation between private and common rooms, promote natural ventilation due to thermal buoyancy through staircases and double-height rooms and provide an undisturbed outdoor room with a view on the first floor
- Cross ventilation may be achieved by leaving out doorsteps (but beware of sound transfer between rooms)
- See an example in Fig. 30.

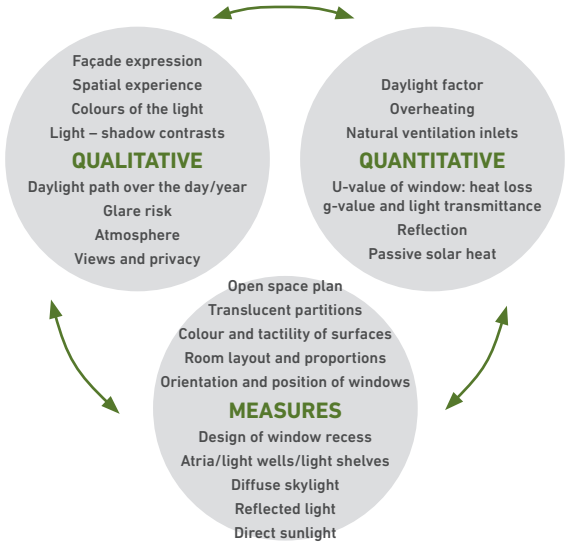
Fig. 30. A built example of a compact building is the Comfort House at 49 Stenagervænget, Vejle, Denmark which is built according to the Passive House standard.

DAYLIGHT, SPACE AND FUNCTION

When working with daylight in a dwelling is essential to create good and varied daylight conditions and to enable the control of direct sunlight and passive heat gain, so as to ensure optimal conditions in terms of comfort and energy.

Daylight is crucial for our perception of space and materials; changes in expression and atmosphere caused by changes in light patterns over the day and year create variation in the experience of space, which makes architecture come alive. Daylight is of great importance to our physical and mental wellbeing; it regulates our circadian rhythm and may help prevent stress and depression (Madsen & Hansen 2011). Moreover, daylight is a free resource providing lighting and passive solar heat. As a minimum, daylight in a house must comply with the requirements set by the building regulations. Overheating and glare poses a challenge.

ASPECTS IN PLAY



Hence, it is important from the beginning of the design process to formulate a daylight strategy taking into account both qualitative and quantitative aspects of daylight.

USING THE DIFFERENT DAYLIGHT QUALITIES

By nature, daylight is dynamic; its intensity, direction and colour vary according to time and weather conditions. Daylight is constituted by direct sunlight, diffuse skylight and reflected light.

Direct sunlight is intense, directional, creates sharp shadows and may cause glare. Diffuse skylight is characterised by a cool tone but is well suited for general lighting. Reflected light is light reflected from the outdoor environment and light reflected from surfaces in the room (floor, walls, ceiling). Therefore, surface tactility and colour are crucial. By combining different types of daylight, it is possible to create varied and evocative daylight conditions and to provide a varied experience of the room over the day and year.

FOCUS POINTS

- Size, position and orientation of windows
- Ensuring sufficient daylight on a cloudy day (daylight factor)
- Passive solar heat and excessive temperatures (e.g. control by solar shading and venting)
- Daylight quality (colour, contrasts, daylight path over the day/year)
- Light intensity and glare (e.g. curtains)
- Sense of space
- Room décor
- Views and privacy
- Relation to outdoor spaces
- Façade expression
- Construction of windows/doors (pane, frame, casing)
- Glass properties (colour, g-value and light transmittance).

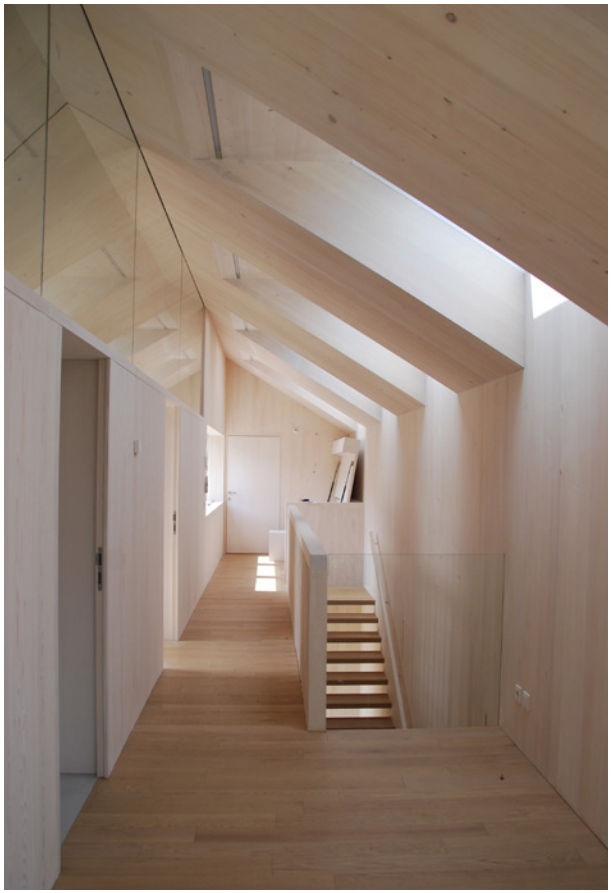
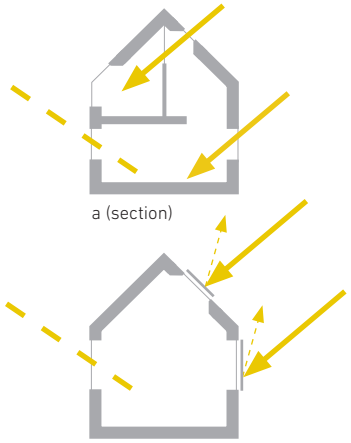


Fig. 31. In Sunlight House, Austria, transverse lighting is ensured by a glass construction in the upper part of the partition. This also adds to the spatiality of the corridor.

Tools for the calculation of daylight may be: VELUX Daylight Visualizer, Dialux, Radience, Daysim, Relux etc.

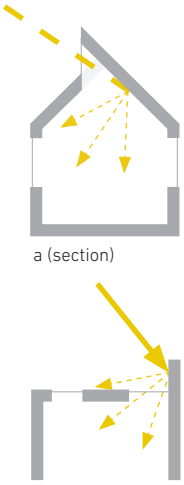
DESIGN PRINCIPLES

ROOMS WITH TRANSVERSE LIGHTING



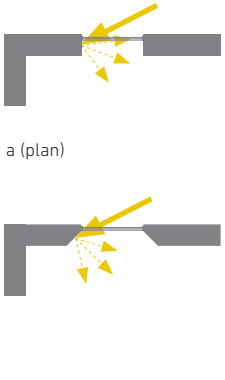
- An open plan with long views is one way of creating rooms with transverse lighting (a). The house will change character as the light passes through the rooms over the day.
- Transparent or translucent glass in partitions will enable transverse lighting in rooms with only one façade (a + Fig. 31).
- Even when solar shading is necessary, a room lit from both sides will be lighted by diffuse daylight (b). This may minimise the need for artificial lighting.

REFLECTED LIGHT



- Reflected light generates general lighting and may refract glare from direct sunlight.
- The light can be reflected deeper into the room via indoor surfaces (floor, walls, ceiling (a + Fig 32)) or via outdoor cantilevered elements and/or light shelves (b).
- How and to what extent light is reflected will depend on the layout of the rom, and on the colour and tactility of surfaces.

WINDOW RECESS



- The transition between window and room surfaces may be designed with different details to greatly impact the inflow of light into the room (a and b). A white window recess reflects light the best
- Changing the angle of the window recess will affect the spatial experience and may enable light to be reflected deeper into the room (b)
- An example is seen in the kindergarten in Langenegg, Austria, where the window frame is retracted so as to enable light to reach even the outermost part of the ceiling surface (Fig. 33).

Fig. 32. Reflected light in Home for Life, Lystrup, Denmark. This house was designed with light inflow from several sides as well as skylight. Be aware of the risk of glare, however.

Fig. 33. Kindergarten in Langenegg, Austria, 2004.

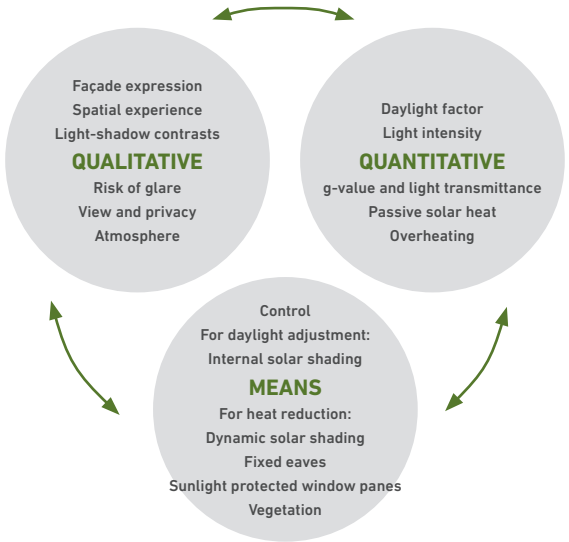
SOLAR SHADING, SPACE AND FUNCTION

When designing to supply sufficient and good daylight, we know that sometimes there will be too much light, which can result in either overheating or glare. It is, therefore, important to integrate solar shading.

Exterior solar shading is an efficient way to prevent overheating. Direct solar radiation will be blocked before it enters the room, and the supply of passive solar heat will be reduced. According to (Jensen & Petersen 2013), exterior solar shading is essential in order to meet the building class 2020 thermal indoor environment requirements and at the same time to ensure good daylight conditions in the house.

Interior solar shading has only limited impact on overheating, as solar heat will already have entered the room. Its primary function is to adjust daylight, to avoid glare and to ensure privacy.

ASPECTS IN PLAY



By combining different forms of solar shading, interior as well as exterior, it is possible to ensure a good indoor environment, minimising the energy demand for cooling and creating evocative light effects. Exterior and interior solar shading can be controlled automatically or manually. One requirement of automatic control should be that users feel they are not losing control.

FOCUS POINTS

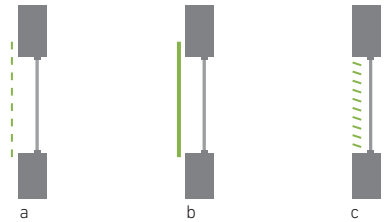
- Impact on spatial experience
- Room orientation
- View and privacy
- Overheating and glare
- Impact on light quality and the light in the room
- Façade expression
- Control – manual or automatic (Users should feel they are not losing control).

Fig. 34. The awning blocks solar radiation but not the view

Fig. 35. Exterior blinds reduce passive solar heat

DESIGN PRINCIPLES CONTROLLING DAYLIGHT

INTERIOR SOLAR SHADING

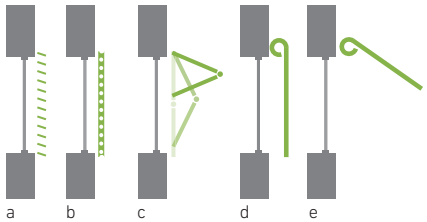


- Reduces solar heat by 10 to 20% (SBi anv. 202)
- Be aware that interior solar shading allows solar heat to enter the room, which may possibly result in overheating
- A light curtain (a) will protect against glare and visual exposure but not against light and heat
- A dense curtain (b) will protect against glare, visual exposure and light
- Venetian blinds (c) will reflect direct sunlight, thus preventing glare, while enabling view.

Fig. 36. Solar shading is essential for the spatial experience. In this house in Lystrup, Denmark, exterior lamellas and perforated steel plates in combination control the supply of passive solar heat.

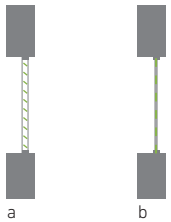
DESIGN PRINCIPLE TO REDUCE SOLAR HEAT GAINS

EXTERIOR SOLAR SHADING



- Reduce solar heat by 70 to 90% (SBi anv. 202)
- Lamellas (a) and perforated plates (b, c) will preserve a partial view while reducing insolation (Fig. 35)
- Partially transparent exterior textile blinds (d) will preserve a partial view, while reducing insolation (Fig. 35)
- Awnings (e) will preserve a view, while reducing insolation (Fig. 34). Beware of wind speeds
- Dynamic solar shading requires control; manual or automatic
- Beware of maintenance expenses associated with exterior solar shading
- Beware of the wind speeds at which the solar shading should function.

SOLAR SHADING WINDOW PANES

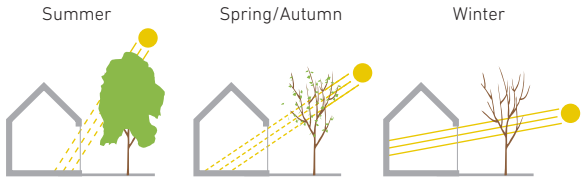


- Solar shading between glass panes (a) requires less maintenance than exterior solar shading, but is not as effective at reducing solar heat
- New technologies (b), e.g. panes with thermo coating, dynamic light transmittance etc. (Winther 2013, Mingzhe 2014)
- Beware that light quality will change. The colour of the light, colour spectrum and light intensity will be reduced.

HORISONTAL EAVES

- Protect against high midday sun in summer
- Have no effect on low morning and afternoon sun in summer: risk of overheating, especially in case of floor-to-ceiling windows
- Do not protect against low spring, autumn and winter sun angles
- Covered outdoor space – extends the building
- Reduce daylight in the building

VEGETATION



- Deciduous trees will reduce insolation in summer but not in winter when more solar heat and light is needed
- A deciduous tree with light foliage filtering the light will provide lively insolation and play of light and shade in the building. For instance: ash, acacia etc. (Fig. 16).

HAVE YOU CONSIDERED...

ABOUT SPACE, FUNCTION, DAYLIGHT AND SOLAR SHADING

- Design, position and orientation of rooms as regards daylight, solar path over the day/year, functionality, layout and variation of rooms, view, privacy, ventilation and duct layout?
- Building design and how it relates to the local architecture (e.g. scale, expression of form, materials), means of access and outdoor space?
- Flexibility of the building with regard to functions and constructions?
- Ensuring good light conditions in the building, amount and quality of light?
- Manual and automatic control of solar shading, which enable control of daylight and passive solar heat gains and protection against visual exposure?

PROCESS

Many of these design parameters are linked to the investigation of the area and the establishment of design criteria - and are therefore established in the early design process.

Design strategies regarding space, function, daylight and solar shading are the core of the sketching phase when the body of the building takes shape. These design parameters are decisive for both building design and the technical performance of the building. Thus, it is essential that regular increasingly detailed calculations are made, investigating the technical performance of the different design proposals.

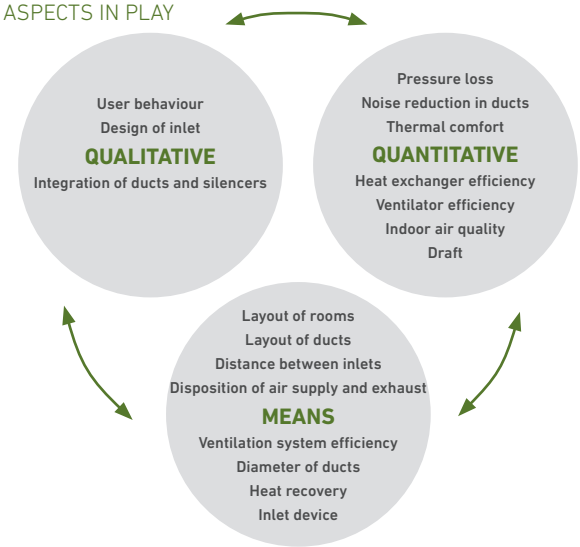
The overall form has been established. The design proposal is concretised and is adjusted with input from simulations and the calculation of daylight, acoustics etc.

VENTILATION

The primary objective of ventilation is to ensure a good indoor environment with high indoor air quality and pleasant temperatures. Choice of ventilation strategy is of great importance for the building design, for the comfort in the house and for the energy use.

Generally, a distinction is made between two ventilation strategies; natural and mechanical ventilation. Mechanical ventilation is used during the heating season when efficient heat recovery will make use of energy from extract air for the heating of supply air, minimising the energy need for heating. Outside of the heating season, or when there is a need for additional air change to avoid excess temperatures, natural ventilation through openings in the building envelope can be an advantage.

ASPECTS IN PLAY



HYBRID VENTILATION

A third strategy which is particularly interesting when working with zero energy houses is hybrid ventilation. This combines natural and mechanical ventilation, making use of heat recovery from mechanical ventilation and the possibility of a large air change without additional energy use in natural ventilation, and is therefore a sensible solution when it comes to both comfort and energy.

Hybrid ventilation does presuppose, however, that the building is designed in accordance with both ventilation strategies, which requires different design considerations in order for optimal functionality to be achieved, technically as well as architecturally. Read more about hybrid ventilation in (Heiselberg 2002 and 2007).

MECHANICAL VENTILATION

When a building is to be ventilated mechanically, considerations of placement, layout and sizing of ducts, silencers, aggregate etc. must be included in the early sketching phase.

In mechanical ventilation with heat recovery, exhaust air heat is used for heating the cold supply air. Thus, the heat recovery system reduces the heat loss by ventilation. The efficiency of the ventilation system depends on e.g. the length and insulation of the air ducts, the dimensioning of the system, user behaviour, control and maintenance, as well as the efficiency of the fan and heat exchanger. It is important to be aware of the possibility of maintaining and cleaning the ducts, as the quality of air will depend on this. To minimise the risk of excess temperatures, the system must include a bypass function, which is used when there is no need for heat recovery.

In general, one of two types of duct layout may be selected; distribution ducts or individual ducts (see design principles for duct layout). Choice of duct layout affects the size of ducts and the location of silencers. It is also possible to choose decentralised systems in individual rooms.

One can advantageously prepare a strategy for the adjustment of air flow depending on:

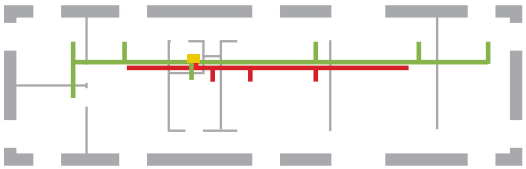
- Functions/needs related to the rooms
- Changes in household (the system must be robust/flexible so as to manage and ensure comfort whether 1, 2 or 5 people are present)
- As regards heating via ventilation, it should be considered when designing the system that a bedroom temperature below 20 degrees should be possible.

FOCUS POINTS

- Ventilation ducts are space demanding and must be integrated in the spatial organisation (see design principles)
- Integration of systems. Systems for houses are available in different sizes, but several system types that will fit into a normal cupboard of 60 x 60 cm exist
- Both mechanical and natural ventilation systems should be designed
- Duct layout (min. pressure loss, min. noise etc.)
- In single family houses, ducts with a diameter of 100 to 160 mm are typically used
- Make sure that space is set aside for silencers. Typically, diameters of round silencers will be 100 to 200 mm larger than the ducts
- In terms of pressure loss, the system should be as symmetrical as possible
- Opportunities for maintenance and replacement
- Bypass when there is no need for heat recovery
- The ventilation system should be placed within the building envelope
- Consider humidity recovery, as air humidity may be very low in winter.

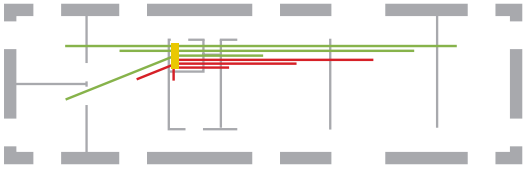
DESIGN PRINCIPLES OF DUCT LAYOUT

DISTRIBUTION DUCTS



- Ventilation with distribution ducts
- Fewer duct metres of larger diameters
- Makes additional demands on spaces for duct layout
- Silencers between rooms + in transitions to ventilation systems in order to minimise noise discomfort to users

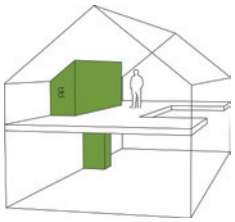
INDIVIDUEL DUCTS



- Individual duct layout to individual rooms
- Additional duct metres of smaller diameters
- Ducts can be placed in smaller cavities
- Silencing can be handled in the utility room

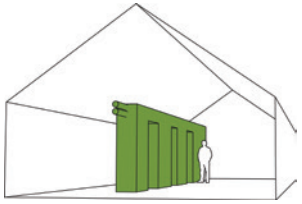
DESIGN PRINCIPLES FOR THE INTEGRATION OF DUCTS

SPACE UNDER THE EAVES



Ducts may be placed in roof slope space etc. where zones with for instance low ceiling height may be utilised and supplement the utility room of the building.

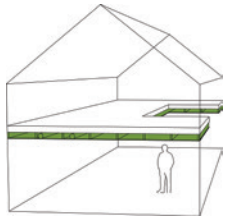
MULTIFUNCTIONAL ELEMENT



The ducts may be integrated in a multi-functional longitudinal element, e.g.:

- Act as room divider
- Integrate storage
- Include niches
- Allow light to pass from two sides
- Ensure access to the ducts for maintenance.

ALONG BUILDING SURFACES



Ducts may be led along the building elements, e.g.:

- Below floor structure (beware of room height) (Fig. 37)
- Above suspended ceiling sheets in case of a high-beamed ceiling.

SILENCERS MUST MUFFLE:

Noise from ventilation systems and valves
Transfer of airborne sound between rooms
Noise from ducts (should not occur).

Fig. 37. Battens attached below the load bearing floor structure may ensure space for ducts and silencers. Sheathing is mounted underneath.

NATURAL VENTILATION

The role of natural ventilation in zero energy houses is – together with solar shading and possibly cooling – to ensure a good thermal indoor environment without excessive temperatures. Natural ventilation must be designed so as to enable ventilation during the night and when no one is in the house. Outside of the heating season, the building with natural ventilation may be ventilated more than is the case during the heating season, ensuring an even better air quality. In addition, natural ventilation may offer certain experience-related qualities as scents, humidity, variations in wind velocity etc. and hereby enable the sensing of surroundings and weather conditions. It will also enable direct user control of the indoor environment.

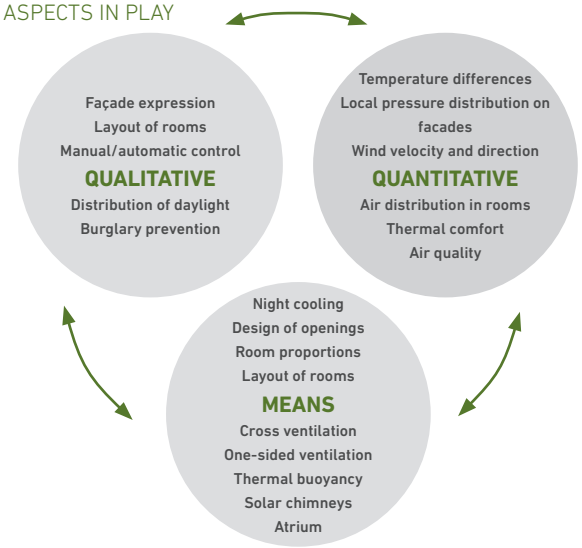
Natural ventilation of the building is an interrelated part of the building design. The efficiency of natural ventilation will depend on many factors, including the surroundings of the building, the micro climate, building design (overall geometry, room proportions, window openings etc.) and control. Read more about natural ventilation in (Heiselberg 2007).

Natural ventilation is driven by pressure differences:

- Caused by temperature differences (thermal buoyancy)
- Caused by wind.

It is important that the house is designed in a way which makes use of both thermal buoyancy and wind pressure, so that the house may be ventilated when there is no wind, or when the difference between outdoor and indoor temperature is small. Within natural ventilation, a general distinction is made between three principles; one-sided ventilation, cross ventilation and thermal buoyancy (also known as the chimney effect) (Fig. 38). Generally, a combination of the principles is used. The following calculation tools may be used: BSim, CONTAM, COMIS, Energy+.

ASPECTS IN PLAY



FOCUS POINTS

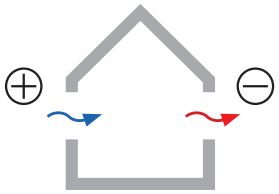
- Utilize varied spatialities – staggered levels, double height rooms etc. – to ensure good natural ventilation. NB Remember that warm air moves upwards!
- Air transfer between rooms
- Openings (typically windows) must be designed to enable the desired air change
- Automatic or manual control, possibility of user control
- Manual control may cause poor indoor environment (overheating and poor air quality) or an increase in energy consumption. Manual control also requires user participation and knowledge of the systems
- Ventilation must be burglar-proof to enable night time ventilation if needed and ventilation when no one is in the house.

Fig. 38. A solar chimney may increase natural ventilation by thermal buoyancy.

Fig. 39. In this house, shutters are included in the window design. The windows cannot be opened; instead ventilation takes place by using a hatch behind the shutters. The shutters can be opened or locked as required.

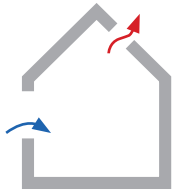
DESIGN PRINCIPLES

CROSS VENTILATION



- May occur in case of openings in two or more exterior walls/roof surfaces
- Outdoor air will enter through openings on the windward side (+) and exit through openings on the leeward side (-). It is therefore important to make sure that the geometry, orientation and micro climate of the building supports this principle
- Room depth should not exceed 5 x room height.

THERMAL BUOYANCY

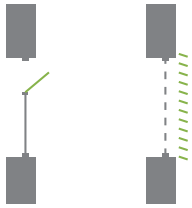


- Ventilation is caused by thermal buoyancy
- Dependent on; the area of the ventilation openings, temperature differences of indoor and outdoor air, and differences in height between the openings
- The spatial organisation of the house and the design of the ventilation system must ensure that polluted air does not travel to other rooms
- In case of more than one floor, the top floor will be the warmest. This should be considered in the spatial organisation.

ONE-SIDED VENTILATION

- Is applied in rooms with openings in one façade
- Ventilation is caused by wind, thermal buoyancy or a combination of these
- Room depth should not exceed 2.5 x room height
- The least efficient of the three ventilation principle

NIGHT COOLING AND BURGLAR PROTECTION



- Narrow windows (horisontal or vertical) may ensure night ventilation when required, as well as ventilation when no one is in the house
- Fixed shutters covering openings is another alternative (Fig. 39).

HAVE YOU CONSIDERED...

ABOUT VENTILATION

- A building design enabling hybrid ventilation?
- Layout, design and sizing of ducts that take into account technical performance, maintenance, replacement, etc.?
- Space for and integration of ducts and silencers in the architecture?
- A strategy that allows adjustment of air change? Spatial layout supporting natural ventilation (in summer), cf. the principles regarding thermal buoyancy, one-sided and cross ventilation?
- Designing openings (typically windows) to enable the requested air change when cooling is needed?
- Automatic or manual control? Remember to take user behaviour and needs into consideration.
- Burglar protection of the house to enable ventilation when no one is in the house and during the night?

PROCESS

In the preliminary phases, a cross-disciplinary design team in collaboration with the house owner will decide the overall ventilation strategy; mechanical, natural or hybrid.

The chosen ventilation strategy constitutes an essential design parameter. Calculations of an increasing level of detailing are informing the design.

The design proposal is specified through detailed calculations of the mechanical ventilation system and simulations of natural ventilation. Adjustments in the design may be made.

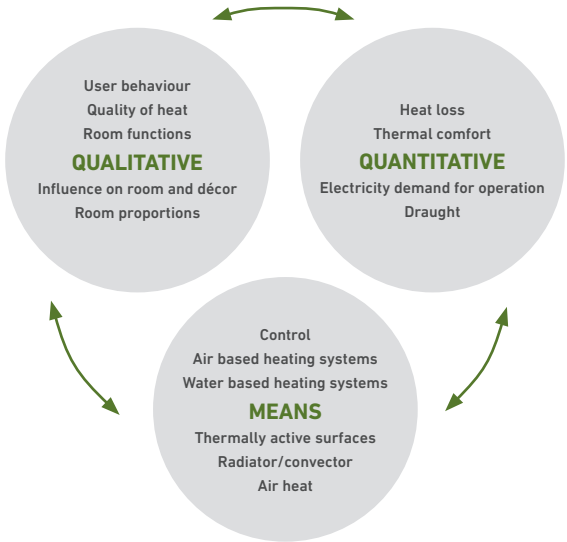
HEATING

In addition to determining the energy supply of a house (see the sections Energy supply – electricity and heat and Heat pumps), designing the heating system of a zero energy building requires selecting a heat distribution method and a method of supplying each room. The type of heating system may have a great impact on the design and construction of the room, and knowledge of the different options, their potentials and challenges must therefore be included in the preliminary sketching phase.

HEATERS

Generally, a distinction is made between air based and water based heaters. These supply heat in different ways (radiation, convection and varying temperature level), which will lead to different levels of comfort and energy efficiency. A selection may be found under Design Principles.

ASPECTS IN PLAY



Comparisons between the two types of heat distribution systems show that several factors speak in favour of water based heating systems. Water based systems are more energy efficient as they operate at lower temperature levels and use considerably less electricity for heat transportation than do air based systems.

THERMALLY ACTIVE SURFACES

Thermally active surfaces may act as heaters when integrated in a building; they may also act as coolers. This technology is commonly known and applied in houses in Denmark, typically as underfloor heating. The technology may, however, also be used for cooling.

Compared with a conventional radiator system, this technology will activate larger areas, which enables low-temperature heating and high-temperature cooling. This technology is used and integrated in the building constructions of other types of building, e.g. office and cultural buildings – either in floors, ceilings or walls; it is 'invisible' and enables 'uncluttered' room design. For more info, see (Jérôme 2014).

It is important that the heating system is not too sluggish (slow in adjusting), so that its heat release will always adjust to the need of the house. However, the best solution for a certain housing project will depend on other factors as well, e.g.:

- Room geometry
- Expected use and furnishing of the room
- Accessible surfaces.

The Design Principles show some examples of common heaters and factors which should be considered as regard to their use in a zero energy house.

FOCUS POINTS

- Choice of heaters is important to architecture, comfort, energy consumption and economy
- A thermally active surface should be as big as possible in order for low temperature heating and high temperature cooling to be applicable
- Outside of district heating areas, and if the energy demand of the house is very low, pure electric heating or air/air source heat pumps for each room (if the house has only few rooms) may be more economical than a complete heat distribution system. This requires, however, that a major proportion of the domestic hot water can be supplied by solar panels
- In case of floor heating, efficient insulation underneath the heating pipes is essential.

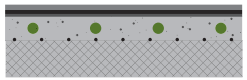
DESIGN PRINCIPLES

UNDERFLOOR HEATING

Generally
- Limited heating and cooling capacity, around 40 W/m²

1. Heating pipes embedded in deck (sluggish control)
- Thermal comfort is not achievable in case of sudden and large variations in heat load
- The principle is also applicable in walls; this is widely used in countries outside of Denmark.

2. Heating pipes mounted on heat distribution plates
- Less time constant (shorter adjustment time).



a. Example of heating pipes embedded in a concrete deck. From above: wooden floor/ tiles, intermediate layer, concrete plate 30 to 70 mm above heating pipes, mesh reinforcement, insulation.

b. Example of underfloor heating in wooden construction. From above: wooden floor, intermediate layer, heating pipes on heat distribution plates, wood boards on joists, tier of beams and insulation.

RADIATOR/CONVECTOR

- A well-known and tested solution for the heating of houses
- Found in a large number of shapes, sizes and designs
- Electric radiators may be economical solutions at very low space heat demands, as in zero energy buildings, or as heat sources in rooms which are rarely heated. Electricity consumption may be compensated by solar cells.

Example of floor convector:
- Placed under a grid in the floor, not taking up space in the room or in front of a window (Fig. 40)
- Due to the low heating demand, no fan is required
- The trench must be well insulated.

Fig. 40. Floor convector.

AIR HEAT

- Air heat is often included in modern zero energy buildings, using heat from exhaust air to preheat the fresh inlet air. Any after-heat may be added as waterborne heat or electricity.
- The design and location of inlet may have a great impact on the room (Fig. 41)
- Heat may be added from water/airborne heat exchangers or directly from the air/ air heat pump in the individual room
- From 2020, air heat must not constitute the only heat source of a building (BR10, 7.2.5.1 subsection 12)
- Individual control must be possible in all rooms
- Be aware of noise from fans and noise transfer between rooms (see the section on Ventilation)
- The design air inlet temperature must not exceed 35°C. (DS 469).

Fig. 41. Example of inlet mounted above cupboard unit.

HAVE YOU CONSIDERED...

ABOUT HEATING

- Should the heating system of the house be primarily air based or water based?
- How may installations be integrated?
- Control of installations? Remember to take user behaviour and needs into account.
- That sufficient space is set aside for central installations such as tank and heat pump (service conditions).
- Type of heating system, considering requested comfort level?
- A simple installation solution? Complicated installations often result in errors during installation and operation.

PROCESS

In some cases, the choice of heating system is already made in the preliminary phase, possibly based on requests made by the house owner.

Choice of heating system is made in the sketching phase (at the latest) to make sure the system can be integrated in the construction and design of rooms. For water based heating systems, it must be determined how pipes are integrated in constructions, and possibly which surfaces should be thermally active. For air based heating systems, duct layout and dimensioning in the rooms must be taken into account.

The heating system is optimised.

MATERIALS AND ACOUSTICS

In order to achieve a sustainable building design, it is important to consider the impact of the building materials on the environment and the surroundings, including the indoor environment and acoustics as well as the user's sensuous perception of the house.

MATERIALS

Clarifying a material's complete environmental impact may be a very comprehensive procedure, but surveys of the LCA (Life Cycle Assessment) of different materials are continuously being developed, and these are included in certifications such as DGNB. A concept like Cradle to Cradle® goes a step further as regards the sustainability of materials. The Manual "Cradle to Cradle® in the built environment" (Jørgensen & Lyngsgaard 2013) provides an insight into the way in which this concept may be implemented in practice.

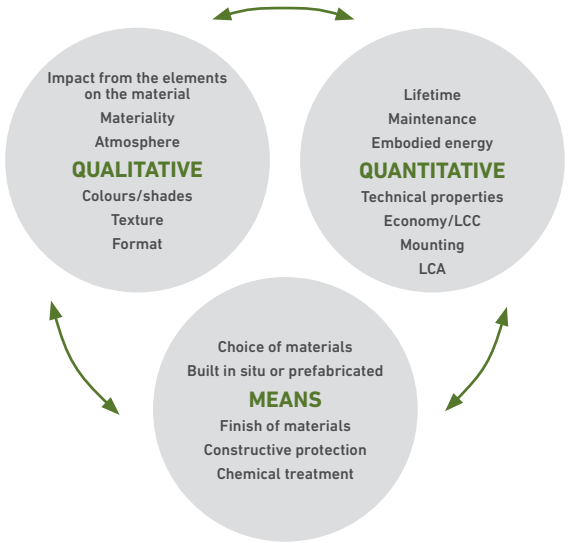
Materials are the basis of architecture. Materials form space, and the play of light in materials adds character and atmosphere to the room. Materials are what we meet – sense, touch, walk on and smell – and in combination with the shape and proportions of the room, materials define the acoustics of the room. For the optimal use of materials in a building, we must know their properties. The model (Fig. 42) lists a number of essential material parameters and may contribute to the clarification and articulation of qualities which are decisive for our application and experience of a certain material in an architectural context (Fig. 43).

Another important aspect as regards the sustainability of a material is its transformation over time when exposed to the elements. All materials require maintenance, although the need may vary greatly. Knowledge of the property of materials and the climatic conditions of the site are therefore important.

FOCUS POINTS

- The desired appearance of the building
- The technical properties of the material
- The character (sensuous properties) of the material
- The processing of the material (format/module, mounting etc.)
- Patination
- Acoustics
- LCA of the materials
- Degasification of materials
- Possible recycling
- Maintenance.

ASPECTS IN PLAY



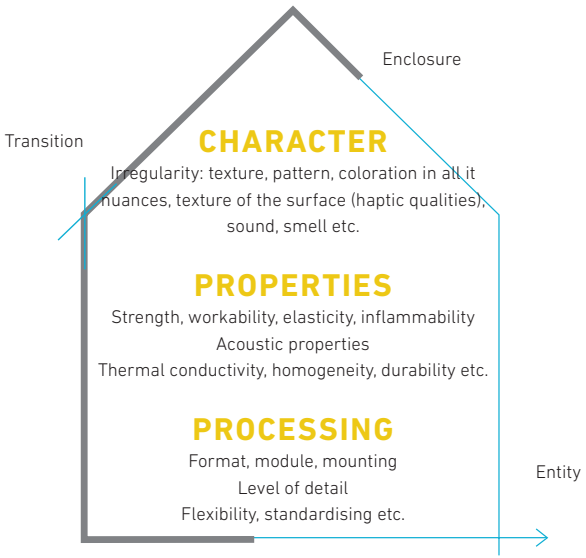


Fig. 42: A model for analysing and evaluating a materials materiality (diagram based on Bejder 2012).

Fig. 43. The appearance of a building will vary greatly, depending on the material, its shape, processing, level of detail and context.

Fig. 44. Today, many houses are built with large open spaces and hard materials (e.g. tiled floors, smoothly plastered walls and ceilings), which often results in poor room acoustics. Sound absorbing acoustic panels (as in the picture) is one way of achieving better room acoustics. Carpets, soft furniture and pictures may also help.

ACOUSTICS IN HOUSING

Acoustics is often an ignored issue in house building, particularly in the case of single-family houses. However, acoustics is of great importance to the indoor environment and consequently to the sustainability of zero energy buildings. Additionally, acoustics can be an effective means of underlining the character of a room. Acoustics cover: room acoustics (Fig. 44), building acoustics and noise from installations.

ROOM ACOUSTICS INCLUDE:
- Reverberation time
- Speech recognition

Be aware of the risk of poor room acoustics in case of:
- Large rooms
- Parallel surfaces
- Hard materials

BUILDING ACOUSTICS INCLUDE:
- Noise from the surroundings (neighbours, traffic, etc.)
- Step sound (typically between two floors)
- Airborne noise (music, appliances etc.)
- Vibrations

May be muffled by:
- Soundproofing between rooms
- Construction details: prevent sound transmission

NOISE FROM INSTALLATIONS INCLUDES:
- Ventilation systems (see section on Ventilation)
- Heating systems
- Domestic water systems

May be muffled by
- Silencers in mechanical ventilation systems (see section on Ventilation)

HAVE YOU CONSIDERED...

ABOUT MATERIALS AND ACOUSTICS

- Choice of material(s) with regard to properties, processing and character?
- Use of materials with regard to properties, processing and character?
- Environmental impact of materials?
- Patination of materials? Does the material in question require special conditions with regard to construction details or chemical protection etc.?
- Layout of rooms and choice of materials with regard to room acoustics?
- Layout of constructions and installations with regard to building acoustics and noise?

PROCESS

Considerations regarding materials are included throughout the process. In the preliminary phases, considerations regarding materials will emerge from site analyses, owner's wishes and the design team's immediate and intuitive perception of the project. Later considerations are concerned with the choice of construction type; this may also be prompted by wishes for specific materials. Considerations of materials may be both general and specific throughout the design process.

As the project is becoming more specific, considerations will become more detailed, for instance with regard to the joining of materials in a way which accommodates both technical aspects and aesthetic synthesis between detail and entity.

Considerations regarding acoustics are included under general considerations of materials, i.e. during the entire process. Moreover, room acoustics are an important design parameter with regard to room design and proportions.

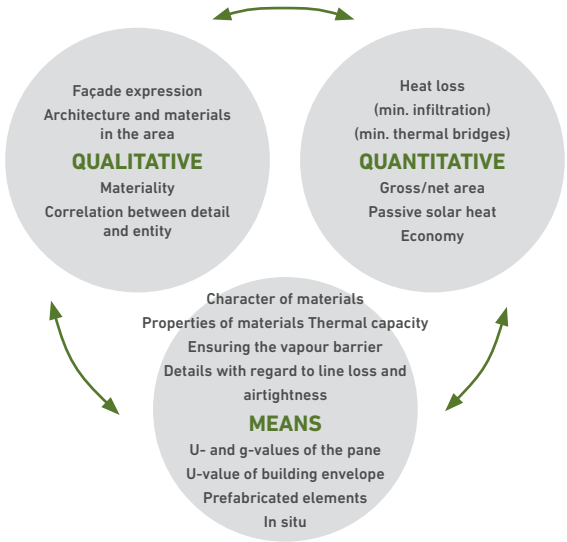
BUILDING ENVELOPE

The constructional design of the building envelope of a Zero Energy Building is decisive for the appearance as well as for the energy demand of the building.

The building envelope is a building's external membrane, which controls and adjusts heat, light and air in the residence. The building envelope consists of:

- Exterior walls, roof, ground deck. These will determine the level of heat losses
- Openings (windows and exterior doors). These will determine the level of heat losses, and the inflow of heat and light.

ASPECTS IN PLAY



Considering the stricter requirements with regard to the energy demand of buildings, building designers can chose between two approaches;

1. We can develop our methods when using old (well-known) building materials. Typically, this will require extra insulation and special care as to details in order to prevent thermal bridges and leakage.
2. We can use new materials and take advantage of the properties of the individual materials. This primarily requires new knowledge and an open mind.

The highly insulated and thick building envelope is often the subject of much criticism, not least because it reduces the net area of the building. However, apart from its effect on the energy use, the thick building envelope may also constitute an architectural and comfort-related potential.

From being merely a surface that defines the boundaries of a space and the transition between inside and outside, the building envelope may constitute a space in itself, due to its depth. Highly insulated windows minimise the risk of cold downdraught, causing zones close to large glass areas to offer comfortable conditions. These niches enable the staging of special spatial experiences – a defined space in the light, on the border between the house and its surroundings (Fig. 45).

FOCUS POINTS

- Highly insulating (low U-value)
- Minimising thermal bridges
- Minimising infiltration (leakages in the envelope)
- Should the construction be expressed in the architecture?
- Should the building be erected in situ?
- Should prefabricated elements be used?

INSULATING LEVEL OF BUILDING ENVELOPE EXCL. WINDOWS AND DOORS

Building Class 2020:

1 storey:	Average U-value: 0.12 W/(m²K)
2 storeys:	Average U-value: 0.15 W/(m²K)
3+ storeys:	Average U-value: 0.18 W/(m²K)

AIRTIGHTNESS

Building Class 2020: max. 0.5 l/s per m² at 50 Pa pressure difference

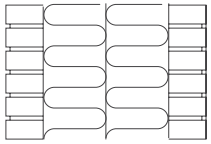
Focus on:

- Limiting penetration of the airtight layer
- Ensuring the vapour barrier (e.g. where installations penetrate it)
- Design which supports buildability.

Fig. 45. The thick building envelope and the highly insulated windows minimise cold down-draught and enables new spatial opportunities as demonstrated in this picture from the Cancer Counselling Centre in Næstved, Denmark.

DESIGN PRINCIPLES

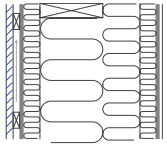
HEAVY CONSTRUCTION



- Example of heavy construction: Brick, insulation, brick: U-value 0.086 W/m²K, thickness ~ 600 mm. Heat capacity: 204 Wh/m²K. (Larsen & Brunsgaard 2010)

General properties of heavy constructions:
- Heat storage capacity: 120 to 160 Wh/m²K. (SBi anv. 213)
- Buildings with heavy constructions (for instance Fig. 46) require a special focus on the removal by ventilation of excess heat, i.e. by night cooling.

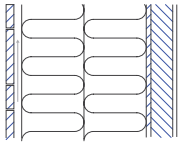
LIGHT-WEIGHT CONSTRUCTION



- Highly insulated construction with a framework of wood or steel. Example of lightweight construction: timber construction, insulation, sheathings: U-value 0.096 W/m²K, thickness ~ 500 mm. Heat capacity: 84 Wh/m²K. (Larsen & Brunsgaard 2010)

General properties of light-weight constructions:
- Heat storage capacity: 40 to 80 Wh/m²K. (SBi anv. 213)
- (Often) several layers with individual specific functions
- The constructive principle of the building is hidden in the building envelope and is not an exposed architectural element
- The expression of the building lies in the composition of volumes and in the encounter between surfaces, their finish and character (Fig. 47).

PREFABRICATED ELEMENTS



Example of prefabricated construction: cross laminated timber element, insulation, sheathing: U-value 0.092 W/m²K, thickness ~ 550 mm. Heat capacity: 120 Wh/m²K. (Larsen & Brunsgaard 2010)

General properties of prefabricated elements:
- Prefabricated elements may be delivered with a very high degree of completion, i.e. high quality control and less dependent on weather conditions
- Max. element size based on transportation considerations
- Plane elements or room modules
- At a very high completion degree, the expression will often be defined by the jointing of modules.

Recent development
- Sandwich element with high-strength concrete
  E.g. Connovate developed by Arkitema, Abercon and Contec. For instance prefabricated element thickness of 340 mm with insulation capacity corresponding to 620 mm traditional heavy construction
- Cross laminated timber elements.

Fig. 46. Heavy construction as massive volume.

Fig. 47. Surfaces intersecting in sharp lines.

THERMAL MASS

Thermal mass acts as energy storage in which the energy from the sun is absorbed and stored in the construction for future release during the heating season and storing of surplus heat during the summer, which will be removed by natural ventilation during the night. This will level out room temperatures over the day, and reduce the energy demand for heating as well as minimise overheating.

Thermal mass is obtained through:
- Heavy constructions
- Light-weight constructions with PCM (Phase Change Material), e.g.: a 13mm plaster board with PCM constitutes a thermal mass corresponding to 5 to 10cm concrete.

To make optimal use of thermal mass, the following should be taken into account:
- The sun must strike the surfaces
- Use materials with high heat storage capacity, e.g. concrete floors or tiles are rather efficient.
- Furniture, pictures, carpets etc. will cause a reduction in thermal effect as they prevent the rays of the sun from reaching the thermal mass (they promote good acoustics, however).

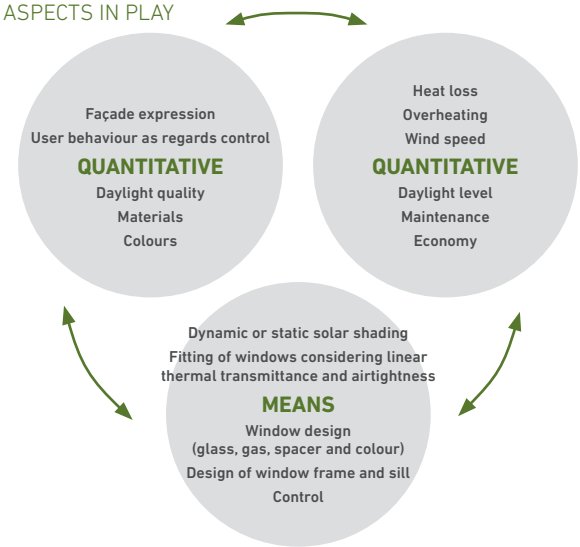
Thermal mass is often mentioned as a quality, but thermal mass in zero energy houses may constitute a problem (Larsen 2011). As the heating demand is very low, there is a risk that a large thermal mass in the building will result in overheating (see p. 19 regarding passive solar heat). If working with thermal mass, it is, therefore, crucial to make sure that surplus heat can be removed by ventilation, e.g. by efficient night time cooling, and to document the indoor environment by use of detailed dynamic simulations.

BUILDING ENVELOPE, WINDOWS, LIGHT AND HEAT

Openings in the building envelope will determine the amount of heat exiting the house as well as heat and light that enter the house; they also provide a view and contact to the surroundings. Low energy windows may vary greatly, and thermal bridges (li- near thermal transmittance) and leakages around windows and doors are relatively important in a highly insulated building envelope (Brunsgaard 2010).

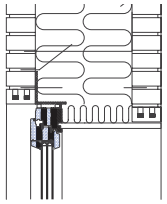
The linear thermal transmittance of a traditional Danish brick recess is approx. 0.1 W/mK (Brunsgaard et al. 2008), which will result in a fairly large heat loss, compared to the total heat loss. Either the heat loss must be compensated elsewhere, or a different mounting solution for the window must be found. The design principles illustrate three possible options and outline a number of technical and aesthetic potentials and issues related to these. Other examples can be found in e.g. (Larsen & Brunsgaard 2010).

ASPECTS IN PLAY



DESIGN PRINCIPLES

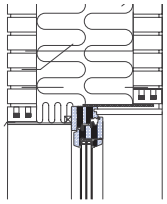
WINDOW PLACED NEAR THE EDGE OF THE FACADE



- Distance window to façade: 0 mm
- Insulated window frame: Yes (on the inside)
- Average linear thermal transmittance (W/mK): ~0.000
- Window opens outwards (Brunsgaard et al. 2008)

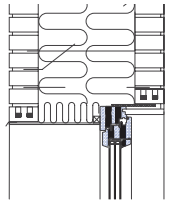
- The deep window sill may be utilised for extra space (seating, extra table depth etc.)
- Plane façade – only slight shadow effect (Fig. 48).

WINDOW PLACED IN THE MIDDLE



- Distance window to façade: 115 mm
- Insulated window frame: Yes (on the outside)
- Average linear thermal transmittance (W/mK) ~0.009
- Window opens inwards (Brunsgaard et al. 2008)
- Allows solar shading to be integrated flush with the façade (Fig. 50).

RECESSED WINDOW



- Distance window to façade: 230 mm
- Insulated window frame: Yes (on the outside)
- Average linear thermal transmittance (W/mK) ~0.008
- Window opens inwards (Brunsgaard et al. 2008)

- Large shade effect in façade (Fig. 48)
- Allows solar shading to be integrated flush with the façade (Fig. 50)
- Depending on the size of the window, the depth of the wall will block the direct sun.

Fig. 48. Example of window placed in the middle and near the edge of the façade.

Fig. 49. Winter morning with hard frost: Triple glazing energy panes do not easily let go of night time rime frost.

Fig. 50. A deep window recess will allow exterior solar shading to be mounted flush with the façade.

LIGHT AND HEAT THROUGH THE BUILDING ENVELOPE

The exterior solar shading will adjust the amount of heat and light passing through the building envelope (see the section on Solar shading). Solar shading may be designed and integrated in many different ways (Fig. 51), and may range from traditional manually moveable shutters to intelligent facades (see Winther 2013 and Mingzhe 2014).

FOCUS POINTS

- Façade expression
- Orientation of opening
- Placement and mounting of windows greatly impact the linear thermal transmittance
- Ensuring the vapour barrier around openings
- Possibly humidity proof window and door grooves
- Ensuring sufficient area and correct location of openable windows for natural ventilation and daylight
- Possibly consider a combination of openable and fixed windows
- Frame; material, frame area in proportion to glass area (frame has a higher U-value than the window pane)
- Pane: number of glass layers, gas, spacer (choose plastic, for instance; available in different colours), coating etc.
- In triple glazed energy panes, condensation and rime frost may block the view in case of hard frost and lack of sun (Fig. 49)
- The need of solar shading
- Automatic or manual control
- Whether solar shading is operated from the outside or from the inside
- Max. wind velocity in which solar shading should be operational.

Fig. 51. In Home for Life, several types of exterior solar shading are combined;
- Fixed eaves towards the south protect against high midday sun in summer and create covered outdoor spaces.
- Sliding shutters with vertical slats protect against sun from the east and west. Manual control.
- Exterior blinds in roof windows and towards the south. Partially transparent to retain a view. Automatic control.

HAVE YOU CONSIDERED...

ABOUT BUILDING ENVELOPE, WINDOWS, LIGHT AND HEAT

- The construction of the building envelope and choice of material, considering heat loss, indoor environment (degassing, acoustics, etc.) and architectural expression?
- The use of thermal mass?
- Be aware of the risk of overheating
- Mounting of windows/doors, considering minimization of linear thermal transmittance
- Securing the airtight layer of the building envelope? Pay special attention to places where the layer is broken (by windows, installations etc.)
- Solar shading as an architecturally integrated part of the building envelope?
- Solar shading, considering need, control, operation and wind velocities at which it must function.

PROCESS

During the sketching phase, different construction methods, types of windows/doors and assembling details are tested; these are considered from the points of view of aesthetics and technical performance. Overall calculations of heat loss and thermal bridges are made.

Possible use of prefabricated elements should be determined in the sketching phase as the size and format of elements etc. may determine the proportions of the building, the rooms etc.

The design and construction of the building envelope, choice of windows and doors and assembling details must be determined when the design proposal is concretised – and not wait to the final project design being made.

ENERGY SUPPLY
DESIGN PRINCIPLES

THE (LOW) ENERGY NEED OF ZERO ENERGY BUILDINGS CAN BE COVERED BY DIFFERENT RENEWABLE ENERGY SOURCES. IN THE FOLLOWING, EXAMPLES OF ENERGY SYSTEMS AND HEATING SYSTEMS OF PARTICULAR RELEVANCE FOR THE ZERO ENERGY HOUSE ARE OUTLINED.

ENERGY SUPPLY, ELECTRICITY AND HEAT

In previous chapters we have considered various steps which may be taken to achieve the best possible design and the best possible indoor environment within the framework of a very low energy demand. In this section we will look into how this (low) energy demand may be covered and accommodated by different renewable energy sources. The energy demand that must be covered includes energy for:

- Heating
- Domestic hot water (DHW)
- Electricity for operation of the building (ventilation, pumps etc.)
- Electricity for appliances (lighting, household appliances etc.)

The energy demand may be covered by connection to the grid (e.g. district heating and electricity grids), by own production on the building and/or on the site or by energy production established by the local house owners' association. In order for a building to be defined as a zero energy building, the non-renewable energy supplied by the grid must be counterbalanced through own production of renewable energy (e.g. electricity production "paying back" to the grid at times when own production exceeds the existing need (cf. definition on page 6)).

According to Mathiesen et al. (2009) the electricity demand of households must be reduced by 50% in 2050 as compared to the 2008 level. Electricity saving appliances are required, but a change in user behaviour is also essential. Moreover, the design of a house can also contribute to a reduction in the electricity demand, e.g. good daylight conditions, space for drying of laundry and possibly innovation-oriented ideas for food storage etc. It is important to find the optimal balance between energy savings and renewable energy production in the building and the interaction, with the energy supply system, so that the total resources are used in the best way possible. No general optimal solution exists for this balance, as this depends on the individual project and the local options. But general comments may be made on the three overall principles:

1. Through design, the heating demand of the zero energy building will be reduced to approx. 20 to 25 kWh/m^2 per year. Reductions to a level below 20 kWh/m^2 per year may cause a comparatively high increase in prices (Aggerholm 2011).
2. The zero energy building is always connected to the electricity grid. In addition, it produces electricity counterbalancing its own energy demand. This may take place either on the building and/or on the site (Fig. 52), by purchase of a share in joint renewable energy production, e.g. the local house owners' association (Fig. 53) or from a share in a wind farm or other energy sources.
3. Use public district heating supply when possible. This is the best socio-economic solution (Lund 2010).

DISTRICT HEATING

District heating in Denmark is in a transitional phase. The current political goals are for all electricity and heating production to be based on renewable energy by 2035 (Our Energy 2011). Low-temperature district heating is expected to constitute part of the solution of achieving a fossil free heating supply by 2035. Moreover, low-energy district heating takes into account reduced heating needs in low-energy buildings, in which traditional district heating is uneconomic. For additional information on low-energy district heating in Denmark, its potentials and related issues, see (Brand 2014).

CONTROL OF ENERGY USE AND PRODUCTION

Seen from a socio-economic point of view, it is important to consider the building an active player in the overall energy system - and not only for energy use and production in the individual house but see them as large groups of "prosumers" and their interaction with the electricity and heating grids. Temporal control of energy use and production is extremely important to avoid peak loads; this will require expensive enhancements of the grids. For the individual house, this will probably be effectuated by the introduction of a control system in the heating and electricity systems that will based on a dynamic price signal and consumer prognoses based on weather conditions and user habits. Maintaining the electricity grid load at a low level during the darkest and coldest winter months will present a special challenge if electricity operated heat pumps become the common heating method outside of the collective utility grid (and perhaps also for electric cars). In this case, good insulation and electricity-saving installations will be a better socio-economic solution than, for instance, compensatory solar PV electricity.

FOCUS POINTS

- Maximum renewable energy plant size allowed
- Calculation method for energy use/production
- How are energy use and production controlled (possibly Smart Grid?)
- Check local rules in force!

ELECTRICITY SUPPLY

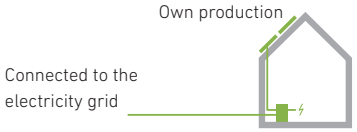


Fig. 52. Energy supply on the building.

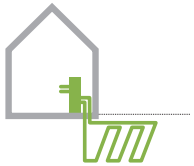
Fig. 53. Energy supply in houseowners' association.

CHOICE OF HEAT SUPPLY AND DISTRIBUTION

No general solution exists for the optimal design of the heating system in a building. Each house requires individual planning/assessment based on the specific local conditions. To support the design of an optimal systems configuration, a method has been developed which assists in selecting and sizing the relevant supply technologies, to make sure that the special prerequisites/demands of the zero energy house are accommodated in the most economical manner. Read more about this in (Milan 2014).

In Fig. 54 possible combinations of heat supply sources and heat distribution systems are illustrated. In principle, all the illustrated heating distribution methods are functional, but they are not all equally expedient in all the supply types shown. The construction and control of the heaters are essential for the energy use.

HEAT SUPPLY

Supply / Distribution	DISTRICT HEATING 	HEAT PUMP (HP) (e.g. ground source) 	HEAT PUMPS (HP) WITH SOLAR PANEL SYSTEM 
Domestic water	At low inlet temperature, special challenges may occur, e.g. the prevention of Legionella bacteria. One solution may be to use a tankless water heater. In addition, this is a more compact solution, compared to a traditional tank solution.	Exhaust air may be used as a heat source by an air/water heat pump	Large sunlight contribution. In summer, the HP will be running very little
High-temperature (HT) heating plant	OK: Radiators, convectors	Only a few HP types are suitable for HT radiator heating; these are not very efficient	Only few HP types suitable for HT radiator heating, not very efficient Small sunlight contribution
Low-temperature (LT) heating plant	Large radiators or thermally active surfaces	Many HP types Large radiators or thermally active surfaces	Many HP types Large radiators or thermally active surfaces A certain direct solar contribution
Air heat*	Heat coil(s) in inlet channel	Heat coil(s) in inlet channel, possibly HP in each room	Heat coil(s) in inlet channel
Influence on building design	Space for tank and/or heat exchanger	See the section Heat Pumps	See the section Solar heating

*Air should not constitute the only heating method.

Fig. 54. Heating supply and distribution of heat.

HEAT PUMPS

When considering how a house should be heated, heating supply and hot water distribution system in the house must be taken into account (see section on Heating). Examples of individual heat supply of the zero energy building are ground source heat pump, air/water heat pump and solar heat (see section on Solar heating).

A heat pump will raise the temperature from a heat source to a higher level at the expense of a certain amount of added high quality energy, usually electricity. The heat pump is interesting for dwellings as it is possible to retrieve approx. three times as much useful heating as is supplied in the form of expensive electricity (Fig. 55). This means that the same money will buy three times as much heat compared to pure electric heat. If electricity for the heat pump is produced in an environmentally friendly way, this heat supply method is fully sustainable. A heat pump operates by gas being compressed and condensed into liquid form in a closed circuit, thereby emitting heat. The lost heat is retrieved from the surroundings by evaporation of the liquid elsewhere in the circuit. The evaporator may be connected to the outdoor air, to exhaust air or to a pipe circuit in the ground, which is cooled in this way during the heating season. In order to harvest as much heat as possible per unit of electricity, it is important that the difference in temperature between the hot and cold sides is as small as possible. Therefore, (relatively warm) soil is a better heat source in winter than outdoor air, and a large underfloor heating system is a better heater than a small radiator. Moreover, it is important that the heat pump runs as continuously as possible, which makes heat pumps with variable rotation speeds more efficient than on/off controlled types. In a heating system based on heat pumps, an electrical heating element will always be available to cover peak loads. Be aware of the electricity use of the heating elements, as this may run out of control.

ASPECTS IN PLAY

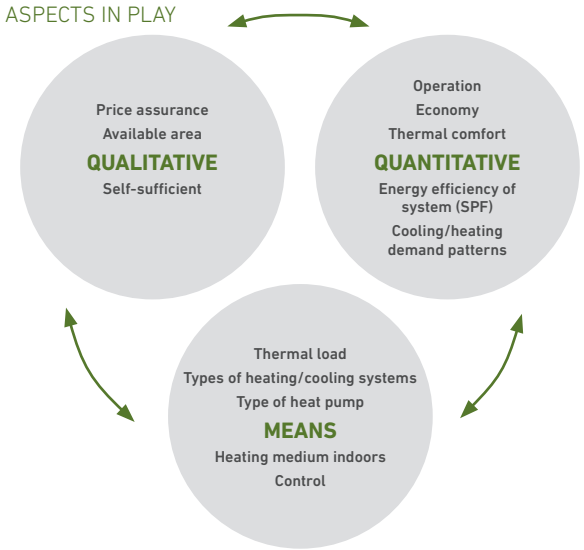


Figure 56 Shows a survey of common types of heat pumps. Generally, liquid based systems are most universal and best suited for all-year operation without auxiliary supply, whereas air based water pumps operate better in the summer months. In all cases, it is decisive for the operating economy that the heating system is correctly designed.

THE GROUND AS A HEAT SOURCE

A ground source heat pump extracts renewable energy from the ground for heating a house. A primary distinction is made between two types of ground source heat pumps; horizontal pipes, and vertical pipes.

The type of system chosen will affect the yield of the heat pump, the energy demand for booster pumps and installation costs. Normally, the choice of the most expedient type of heat pump depends on available area, energy output and financial costs in a life cycle perspective (Pavlov 2014). The heat pump cabinet is only the size of a large refrigerator and may be placed in a basement, utility room or the like.

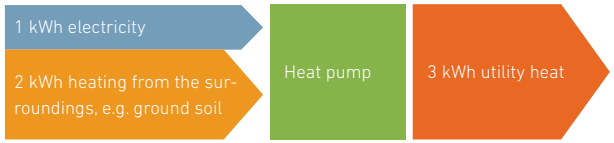


Fig. 55. Heat pump principle.

Heating medium indoors	Heat source for heat pumps (HP)			
	Ventilation air	Outdoor air	Ground source/horisontal pipe	Ground source/vertical pipe
Air	X (auxiliary heat)	X (decentralised HP)	(X)	(X)
Water	X (only domestic water)	X (centralised HP)	X	X (rare)

Fig. 56. Overview of common types of heat pumps..

Software tools such as EED and TRNSYS allow building designers to assess – at different levels of detail and complexity – the performance of the plant as well as different operation and control strategies and therefore contribute to securing the integration of all factors and the energy efficiency and long-term sustainability of the system (Pavlov 2014).

The investment costs of ground coupled systems are high, compared to those of conventional HVAC systems. In return, provided they are correctly constructed, they may result in considerable reductions in operating and maintenance costs. Operating costs are affected by the price of electricity and by the efficiency level of the heat pump system (SCOP) (Pavlov 2014).

DESIGN PRINCIPLES

GROUND SOURCE HEAT PUMP

VERTICAL PIPE

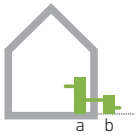
- Single or double U-pipe (PEX pipe) heat exchanger is inserted in a vertical bore hole (30 to 200m)
- Is typically used in case of a limited area. After installation, the bore hole will take up no more space than four traditional garden slabs.
- Boring costs are a significant drawback of this system.
- Requires water-based heaters, e.g. radiator or underfloor heating.
- Risk of contamination of groundwater in case of leakages between bore hole and soil – requires very careful execution.

GROUND SOURCE HEAT PUMP

HORISONTAL PIPE

- PEX pipes are buried in trenches, typically at a depth of 0.6 to 1.5 metres
- Will typically require a ground area of 15 to 20 m^2 per MWh annual heat demand, including hot water (Jensen & Lindholm 2011)
- Directly linked to the local climate conditions, due to the low installation depth
- Installing this system is more expensive than installing an air/water heat pump, but it is also more efficient
- Requires water-borne heater, e.g. radiator or underfloor heat.

AIR/WATER HEAT PUMP



- Indoors (a): hot water tank and room heating
- Outdoors (b): heat pump with fan. Must be integrated in the architecture of a house.
- Be aware of noise from the fan when deciding on the location of the heat pump.
- Installing this system is cheaper than installing a ground source heat pump, but it is also less efficient, as it is affected by low outdoor temperatures and air humidity
- Requires water-borne heater, e.g. radiator or underfloor heating.
- Uses energy for defrosting.

HAVE YOU CONSIDERED...

ABOUT ENERGY SUPPLY AND HEAT PUMPS

- Choice of collective (e.g. district heating) or individual heat supply?
- Local regulations applying?
- Size of plant permitted?
- Payment method?
- Control of consumption and production? Check rules in force!
- Choice of heat source for heat pump?
- Installation informing the user when electric heater is being used – and the price of this?

PROCESS

In the preliminary phases, connection options and planning legislation should be investigated.

The potential use of heat pump (e.g. attached to geothermal heat) should be investigated in the very early phases of the design process when building designers and consultants have the most freedom to make process decisions. This will facilitate the design of optimised installations, process strategy and control systems, enabling optimal use of the potentials and qualities of the system.

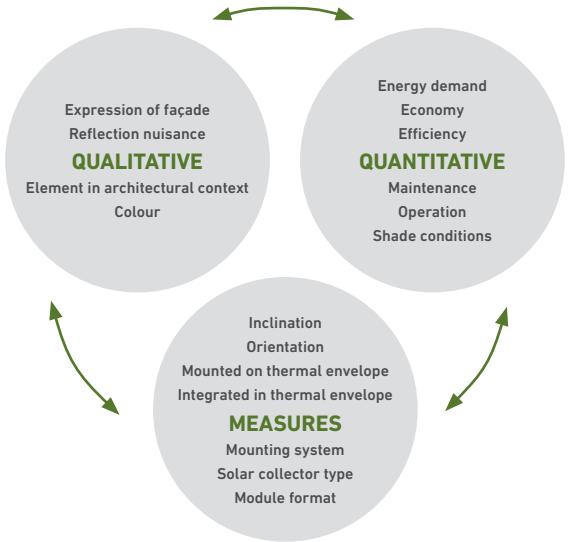
The project proposal is specified through detailed calculations, and the systems are designed.

SOLAR HEATING

Solar heating may serve as a good supplement to the energy supply of a house, provided it is adapted to the design of the building, and the consumption of the inhabitants. Solar collectors convert solar energy into heat with no other energy use than a small amount of electricity used by pump and control system.

Solar thermal systems may be divided into two categories; plants for domestic hot water (DHW) and space heat + DHW (fig. 57). Solar heat for comfort cooling is also possible, but not yet common in the Danish market. On the basis of the expected user pattern and possible expected energy need for heating, it is estimated which of the two systems is required. This provides an early (rough) outline of solar panel area, tank volume and optimal incline of the system; knowledge that can be included in the design of the overall geometry and orientation of the building.

ASPECTS AT PLAY



Solar heat must always be supplemented by another heat source. In that connection it is important to look at the cost of the heat produced compared to cost savings gained by the solar heat, see figure 58.

The yield of the solar thermal system is dependent on the inclination and orientation of the system (fig. 59) and to a great extent on the actual consumption profile. As a rule of thumb, in order for the investment to be profitable, a house should be inhabited by at least 3-4 people with a normal consumption of DHW. A typical solar thermal system of 4 m² for DHW could produce up to 2000 kWh/year.

YIELD AND CONTRIBUTION RATIO

Due to the low space heat demand in a zero energy building, the total contribution ratio for the heating of domestic water and space heating may approach 50% with a well-designed solar heat system. In practice, a higher contribution ratio is only achievable in very large collective systems with seasonal storage.

Compared to an electricity-producing solar photovoltaic system, a solar thermal system will deliver 2 to 4 times more energy per m², but "only" as warm or hot water. For a solar PV system combined with a heat pump, the same heat yield per m² will be achievable, as the heat pump will typically convert one part electricity into three parts heat.

	System for domestic hot water	Systems for room heat and domestic hot water
Use	Is sufficient for houses with a very low heat demand as very little solar energy is available during winter months when there is an actual need for heating.	May be the better choice in case of a certain space heating demand during the summer period, e.g. for tile-covered floors.
Solar panel area	Approx. 1 m² solar panel per person in a household; typically 4 to 5 m² per house	Approx. 2 m² solar panel per person in a household; typically 7 to 12 m² per house
Tank volume	Approx. 50 l/m² solar panel	Approx. 50 l/m² solar panel
Optimal placement	Shadeless, southward approx. 45 degrees from horizontal	Shadeless, southward approx. 60 degrees from horizontal

Fig. 57. General guidelines for sizing solar collectors.

Basic supply	Financial considerations	Technical considerations
Direct electricity heat	Nearly always a good idea	Unproblematic
Electricity driven heat pump	Good idea with large summer consumption	Preferably choose a total solution
District heating	Not normally profitable	Reduced cooling

Fig. 58. Financial and technical considerations involved in a number of basic supply options for the supplementing of solar heat.

USING THE SYSTEM

Compared to the control of other appliances, a solar heating system requires very little of the user. The most important thing is to keep an eye on the system pump to make sure it only operates in sunny weather and that it shuts off during the night. If an electric heater is available for supplementing heat, it is important that this is only active if no other heating options exist. Moreover, solar panel circuit pressure must be read occasionally.

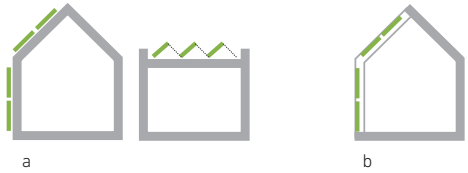
FOCUS POINTS

- Most solar collectors appear as mostly black elements of 2 to 3 m^2, but the appearance of frames, mounting and piping may vary greatly
- The impact of orientation and inclination on yield, see Fig. 59
- Solar panels should be mounted in shadeless locations, but their yield is not so sensitive to partial shade as solar cells
- It is important that the distance from solar collectors to tanks and heat exchangers is not too large, and that pipes are well insulated
- If tank and pipes are insufficiently insulated and mounted on the inside of the building envelope, this may cause overheating during the summer
- The tank should be placed in a utility room and will replace the hot water tank of the basic supply. In case of a large solar heating system, more space should be set aside for the tank compared to that required for a traditional heating system
- The appearance of solar collectors with vacuum tubes is very different from that of traditional flat solar panels; typically these are up to 30% more efficient than standard flat solar panels, measured relative to transparent area.

Fig. 59 (right): Indicative systems' yields at different orientations and inclinations, compared to the optimal yield at 45 to 60° towards south [%]. May be used for both domestic hot water systems and small combination systems when the design is developed, as there is little difference in angle correction (www.altomsolvarme.dk).

DESIGN PRINCIPLES

MOUNTED OR INTEGRATED IN THE BUILDING ENVELOPE



- The solar collectors may be mounted on the roof or on the façade (a)
- Flat solar panels for roof integration are available at additional cost(b)
- Solar panel installations may be mounted in vertical or horizontal groups, adapting it to the lines of the house
- Some solar panels follow the format of specific skylight windows, combining skylight and solar panels in a homogeneous visual element. (Fig. 60).

SOLAR COLLECTOR INSTALLATION AS AN EXTERNAL ELEMENT

- The solar panel installation may be mounted on secondary buildings (c) (e.g. on a garage or garden shed), offering more freedom in building design, choice of orientation and roof inclination etc.
- Solar panels may be installed as free-standing systems on the individual site or in a common site shared by several building owners
- Be aware of the distance from solar panels to tank and system, and make sure pipes are insulated
- Point of departure: the larger the consumption and size of solar heating system, the more favourable the economy (d).

Inclination° / Orientation	South	Southeast / Southwest	East / West
15	90	87	79
30	97	91	78
45	100	93	76
60	100	91	72
75	95	85	66
(Vertical) 90	84	75	58

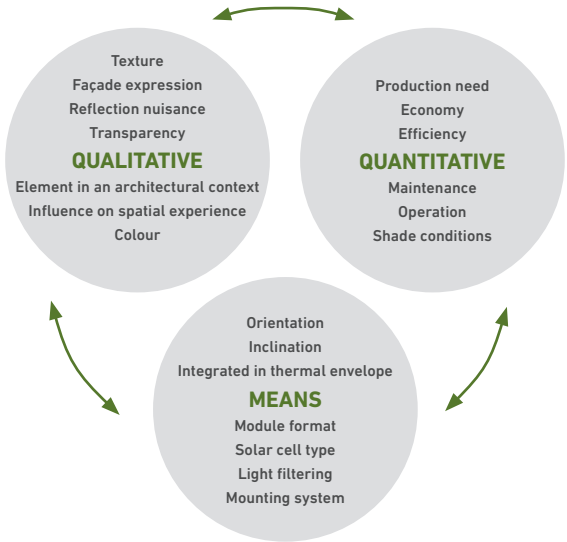
Fig. 60. Solar panels in combination with skylight windows. Home for Life, Denmark.

SOLAR PHOTOVOLTAICS

Solar photovoltaics (PV) systems have become a popular technology for own production of electricity in Denmark, due to high electricity prices/fees and (until recently) good conditions for sale to the grid. With a solar PV system, users are less dependent on fluctuations in energy prices as they produce their own electricity. Moreover, an immediate feeling of contentment may be experienced by the users from supplying some of the energy they are using.

Unfortunately, solar PV panels often appear to be foreign elements, unrelated to the architecture in which they are placed. A more integrated architectural solution may be to view PV modules as not only energy producing technology, but rather as a building material with aesthetic and technical qualities and limitations that must be known in order to use them best.

ASPECTS IN PLAY



FOCUS POINTS

- Orientation and inclination will affect yield (Fig. 61)
- Choice of PV technology, e.g. efficiency, price, appearance (Fig. 62)
- Format. Custom-designed panels are considerably more expensive than standard panels (at present), but an aesthetically well integrated solution may require custom-design. Combining different formats and inclinations requires special attention.
- Shade conditions. Even partial shade caused by neighbouring buildings, trees, chimneys, battlements, dormers etc. may reduce efficiency considerably (Dyck-Madsen & Bøndergaard, 2012). A detailed analysis is therefore important for a realistic assessment of the expected yield.
- Bushing and mounting (watertightness and strength)
- Maximum solar cell panel temperature may reach approx. 80°C. Therefore ensure that thermal extensions of materials do not harm the panels or remaining part of the building.
- Maintenance. Smooth PV panels with an inclination of min. 20 degrees are considered to be largely maintenance free.
- Check rules in force for the use of PV systems in a specific area and for delivery to the grid.

	West	W-SW	S-SW	South	S-SE	E-SE	East
Inclination° /Orientation	90	60	30	0	-30	-60	-90
(Horizontal) 0	85	85	85	85	85	85	85
15	83	89	93	94	93	90	84
35	79	90	97	100	98	91	80
40	77	90	97	100	98	91	79
60	70	83	92	95	93	85	72
75	62	75	83	86	84	76	64
(Vertical) 90	53	63	69	72	70	65	55

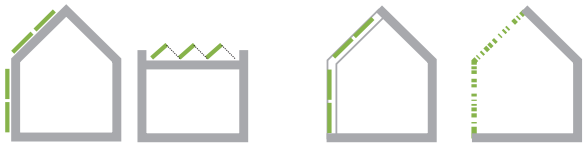
Fig. 61. A PV module produces electricity both in direct sunlight and in overcast weather with diffuse inflow of light, albeit at a reduced yield. Panel orientation and inclination are essential factors that impact the yield of the system. Flexibility is relatively large, as long as this is allowed for in the dimensioning of the overall system. The relation between solar panel orientation and inclination and efficiency appears from this figure. (Typical system calculated with PVsyst5.0 simulation tool (www.pvsyst.com)).

Fig. 62. Survey of different types of solar cells. Properties and expression may vary greatly. The most popular solar cell types are shown along with a selection of their characteristics.

Solar cell type	Area for 1 kW installed power [m²]	Typical annual systems production [kWh/m²]	Appearance/colour	Other
Monocrystalline	5-7	140-190	Black cells on a white or black background	Yield will decrease as temperatures rise
Polycrystaline	6-9	120-150	Dark blue cells on a white or dark background	Yield will decrease as temperatures rise
Thin film, several different types	8-16	50-110	Homogeneous black or brown surface with light striped markings	• Yield will decrease only a little as temperatures rise • Some types are flexible • Low material and energy consumption in production (compared to crystalline)

DESIGN PRINCIPLES

MOUNTED OR INTEGRATED IN THE BUILDING ENVELOPE



- Integrated solar PV systems (b) are the most expensive, and it may be difficult to replace defect components, compared to a system with an open back (a)
- Mounting on a cheap underroof may be a compromise between integration and remounting (Fig. 63)
- In case of façade mounting, special attention must be paid to shade and the risk of vandalism.
- Light filtering solar cells integrated in glass façade (c) (Fig. 64).

PV SYSTEM AS EXTERNAL ELEMENT

- PV modules may function as carport roof (d), pergola etc., providing more freedom in building design, orientation, roof inclination etc.
- Solar PV integrated in solar shading (e) may be relevant if architecturally justifiable. A study of solar PV integrated in wide horizontal revolving slats demonstrates, however, that energy gains are relatively modest, and that the solution requires a special focus on the reciprocal shade of slats, reductions in passive solar heat, daylight and glare (Johnsen et al. 2012).

YIELD AND CONTRIBUTION RATIO

Grid-connected solar PV systems are grateful calculation and estimation objects, as yields are always saleable. Although annual yields may be calculated quite precisely, financial savings are rather difficult to determine as transfer prices of bought and sold electricity are no longer identical. For a typical household, a realistic estimation will be that 30% may be used directly, which makes this part comparable to electricity savings. The remaining 70% may either be sold at the going rate, or disposed of by compulsory sale as heat (domestic water or heavy underfloor heating). The figures in question apply to a system which on an annual basis counterbalances the annual electricity need. The need of household electricity may be 4000 kWh, for instance, which may typically be covered by a system of 5 kW and an area of 40 m^2.

Fig. 63. Solar PV panels used as roof surface. Sunlight House, Austria.

Fig. 64. Solar PV used for glass covering of outdoor space. Light active house, Germany.

HAVE YOU CONSIDERED...

ABOUT SOLAR THERMAL/PV PANELS

- Is the use of solar thermal/PV panels permitted in the area? Check rules in force!
- Is it possible to combine the desired geometry and appearance of the house with solar thermal and/or PV panels?
- Current rules regarding the settlement of electricity delivered to the grid?
- Whether solar collectors or PV modules may function as carport roof, pergola etc.?
- Whether solar collectors or PV modules may bother the neighbours by causing glare?
- Possible savings when choosing an untraditional roof?
- The combination of solar PV + heat pump as an alternative to solar heat?
- Whether attachment is possible to common solar energy system in house owners' association?

PROCESS

It must be checked whether solar panels are allowed in the area (check local development plans), and whether this is in accordance with the wishes of the house owner.

The use of solar thermal/PV panels is important for the overall shape of the building. An early (rough) outline of solar panel area and tank volume is included as a design parameter in the early sketching phase. Paying attention to shade causing elements is also very important.

On the basis of choice of solar thermal/ PV system, and the integration of this in the building, the expected energy use should be calculated. Evaluation and optimisation should be undertaken.

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ILLUSTRATIONS & FOTOS

Anne Kirkegaard Bejder:
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