The Green Village

A proposal for urban
living in dense cities

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A proposal for urban living in dense cities

Abstract

Over the last decade in Denmark, there has been an increased focus on designing low energy houses to achieve a more sustainable way of living. The goal of this thesis "The Green village – a proposal for urban living in dense cities" is to present a reinterpretation of the classic terraced house with close connection to the urban landscape in order to develop a more sustainable, denser alternative way of living to the otherwise more popular Danish single family house.

This thesis investigates the possibility of creating a new, denser way of living in cities so as to reduce the requirement for cars, thereby reducing carbon dioxide emissions. The distinct qualities of the traditional single family house and the terraced house have been merged together to create a new denser typology which can attract families with children.

A survey conducted in Denmark showed that domestic houses are responsible for 30 % of the total energy consumption. Therefore, the focus is on designing and building a house type with a low consumption of energy and heat, containing integrated renewable resources such as solar cells.

The thesis is inspired by two large Danish low energy house projects: a passive house project designed to minimize heat and energy consumption, called "Comfort House" from 2008; and an active house project called "Home for Life" from 2007, which was designed to minimize consumption and is self-sufficient in producing energy and heat.

The lessons learned from these two projects are being used to develop a new version of an active house. The active house concept and integrated design process method have been used to create a holistically designed dwelling that takes account of environment, energy and indoor climate factors. In this thesis, I will use older and newer climate design methods to develop a proposal for a low energy house with a pleasant indoor climate for Danish families to live in.

I use climatic design methods to fulfill the demands for Danish energy class 2020, which stipulates a maximum consumption on 20 kWh/m2 year. I have integrated solar cells and heat pumps in the envelope in order to strive for a house that is self-sufficient in producing both electricity and heat.

The active house concept focuses partly on how to create a link between the houses and the surrounding contexts. To attract families with children to live in a denser way to reduce use of cars, the terraced houses are designed with a strong connection to a designed urban green landscape to create life between the buildings.

Preface

This thesis has been written as a specialization in sustainable low-energy domestic architecture at the Architecture and Design Department of at Aalborg University in the period 2015-2016.

The thesis presents a proposal for an alternative denser sustainable living to the suburban single-family house. This proposal was inspired by two Danish low-energy house projects: “Home for Life”, active house design from 2007; and the “Comfort House”, a passive house project from 2008. The design proposal presented here has been developed in order to show how we can create sustainable dwellings that are pleasant to live for the residents and which promote living in denser cities, thus reducing the need for a car in everyday life.

The connection between houses and urban contexts inspired by the terraced or chain house projects of the 1960s and 1970s, such as the Sjølundsparken in Hellebæk from 1978. The architects behind the project designed terraced houses in order to enhance and embrace the surrounding wild landscape and thereby created life between the houses. The project was strongly inspired by older, spontaneously evolved villages where the space between the houses created social gathering spaces.

The terraced houses are designed following the ‘active house’ concept, implementing old and new climate design techniques to improve the indoor climate. The houses are placed to create social activity between them in the form of green courtyards with playgrounds, social gatherings and deciduous vegetation, including birch trees, beech hedges and fruit bushes. The community house connects the residents, courtyards and houses in a dense green village with relations to the surrounding functionalistic neighbourhood. The parking facilities have been placed in a basement, underneath the urban landscape, and pathways and bicycle sheds have been placed on the site to promote walking or bicycling instead of the car, thus reducing emissions of carbon dioxide.

I have used the integrated design process (IDP) method developed by Mary Ann Knudstrup to create holistically designed houses with a strong connection between the technical requirements, architectural expression and the human behaviour. The houses meet the requirements of the Danish building class 2020, which requires a maximum consumption of electricity and heat of 20 kWh/m2 year. Solar cells and heat pumps are integrated into the house’s envelope to supply the houses with electricity and domestic heated water.

During the writing of this thesis, I have been supported by my boyfriend and family, who patiently helped me through the tough periods. I want to thank my main supervisor Michael Lauring and technical supervisor Peter Vilhelm Nielsen, who have both been extremely helpful and inspiring during the time I wrote this thesis.

This thesis is divided into three parts: an introduction, the presentation of the design and the analysis. In Part I, the introduction, I describe the project on which the thesis is based, the sustainable statement and the location of the project’s site. The presentation is divided into four chapters: the urban layout, the houses, description of the technical details followed by a conclusion and discussion. The second part presents the analysis, which describes the data and concepts used to develop this proposal. The third part contains all the technical drawings with detailed explanations.

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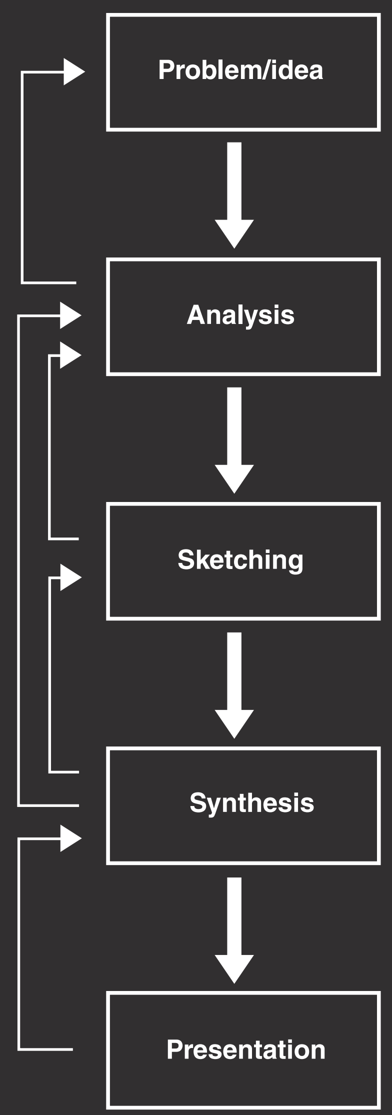


Figure 01, IDP Method

Figure 02, User groups

Introduction

Among most Danish families with children, the preferred choice of dwelling is the single-family house in the suburbs. The suburbs provide a family with their own home, garden, close proximity to nature, a sense of freedom and a safe environment for their children to grow up.

Since the suburbs developed, society has been focusing increasingly on dwellings that consume less energy and heat. The oil crisis in 1973 in Denmark and the famous Brundtland Report on sustainable development from 1989 created a focus on reducing emissions of carbon dioxide, consumption of materials and energy resources.

In 1989, a global survey of 32 major cities showed very close interdependency between the density of population and use of gasoline for transportation. The study concluded that the closer we live together the less fuel we use [Kenworthy & Newman 2006].

Research on sustainability has led to increased focus on how we must change the way we live today in the suburbs, where the car is essential, towards a life style where people live closer together and have all their daily needs at such a close proximity that use of cars can be reduced. By placing houses in close proximity, in the form of terraced houses, more dwellings can be built on one site and material consumption per dwelling reduced.

The focus of this thesis is on two topics which are linked together in this project. The first is how to create sustainable low-consuming dwellings which can become a new interpretation of the suburbs into a more sustainable and denser frame.

The terraced house is an old typology which has been reinterpreted many times through the last century in Denmark. This type of dwelling was developed to accommodate working class families who could live in their own homes in dense cities. Could it be possible to create a merger between the quality of single-family house and a terraced house, to create a new type of dwelling that would be both more sustainable and able to attract families who prefer single-family houses in the suburbs? In the 1960s and 1970s a few Danish architects chose to create an new interpretation of the terraced house by dissolving the strict straight line of houses and create a landscape using the houses and surrounding them with green vegetation. The houses suddenly created the positive green spaces where people could gather in different social contexts.

The second topic of this thesis focuses on creating a dwelling with a pleasant indoor climate using old and new climatic design methods, enabling families to live in homes with reduced consumption of energy and heat. Over the years, Danish building regulations have tightened requirements for energy-efficient housing. The primary goal of this project is to fulfill the demand for the 2020 energy class, which stipulates a maximum consumption of 20 kWh/m2 year without the families' domestic appliances e.g. lighting etc.

I will attempt to achieve this goal using only passive strategies. The secondary goal is to attempt to fulfil the demands for a zero energy house using active strategies such as solar cells to produce electricity and heat pumps to produce e.g. domestic heated water. The following programs will be used to test the energy frame, indoor climate and daylight conditions: Be10, 24hourdaily average spread Excel and Velux daylight visualizer 2.

The method used in this thesis is the Integrated Design Process (IDP) method, developed at Aalborg University by the associate professor Mary-Ann Knudstrup. The method is about how to integrate and optimize the connection between the architectural and technical knowledge in order to create more sustainable holistic designed buildings.

The method consists of five phases: project idea, analyses, sketching, synthesis and presentation phase, se figure 01. The project idea is the goal for the project e.g. how to create sustainable dwelling in a dense urban landscape. The analysis phase is where all the information about the idea is found, such as information about the site, the climate design, which low-energy house concept could be fruitful to work with, etc. The sketching phase is where all the architectural ideas, the technical knowledge and the functional demands are joined together to create several potential concrete solutions.

The synthesis phase is where all architectural and technical demands are completely integrated to create a new holistic, sustainably designed building. Finally, the presentation phase presents the new building by documenting and explaining the design in technical drawings, models or rendered pictures. Knudstrup's five-stage IDP method has been applied in this thesis to ensure holistic designed dwellings that are architecturally and technically well documented [Knudstrup, 2005].

The selected user groups for the project are chosen to ensure that the dwellings are optimal for different family combinations. In the 1960s, a traditional family consisted of working father, a housewife and two children. A lot has changed since then, and the user groups for the house designs to be presented here are based on the present diversity of Danish families, the average working family with 1,73 children [Danmarks statistik 2014] .The main focus in this project is to design homes that can attract families who might otherwise purchase or live in a detached, single-family house, e.g. families with 1-3 children and a pet, see figure 02.

Technical terms in the report

Passive strategies:

Are used to minimize the need for electricity and heat. Passive strategies are e.g. natural ventilation, integrated solar shading or compact climate screen to reduce heat loss.

Active strategies:

They are applied subsequently, so as to provide the building with energy from renewable resources e.g. solar cells, either on-site or off-site.

Holistic design:

Encompasses both the technical and architectural solutions from the very beginning to create an integrated design solution that can minimise energy consumption and provide the occupants with a high quality of life.

Climatic design

This method uses the beneficial elements of nature to create comfortable, energy-efficient and environmentally intelligent buildings. Climatic design uses knowledge about wind, earth, sun, air temperature, moisture and the beneficial effect of plants.

Passive house

The focus is on reducing the requirements for heating by eliminating almost all heat loss through the construction and use the sun for passive heating.

Low energy house

Is defined by the Danish building regulation, which defines how much energy a house is allowed to consume. There are two class: the low-energy class 2015 and the building class 2020

Active house

The focus is on the interaction between energy consumption, indoor climate and the building's impact on the environment. The active house design implements both climatic design and renewable resources to create a self-sufficient building


Figure 03, Courtyard toward south, looing in from west

Vision

"The goal here is to propose a model for a new low-energy house placed in a dense city that can promote a more sustainable way of living as an alternative to the suburb with single family houses. The houses should be placed on a site such that they can create positive spaces between them, which can become green social gathering places for the residents.

The goal is to integrate the technical demands, architectural aesthetics and human behaviour into a holistically designed dwelling with a pleasant indoor climate all year round. The designed houses should offer the same benefits that make the single-family house so attractive to families with small children."

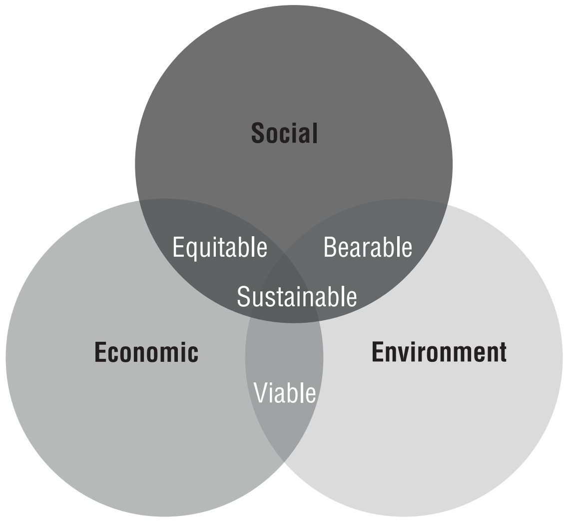


Figure 04, The three spheres of sustainability

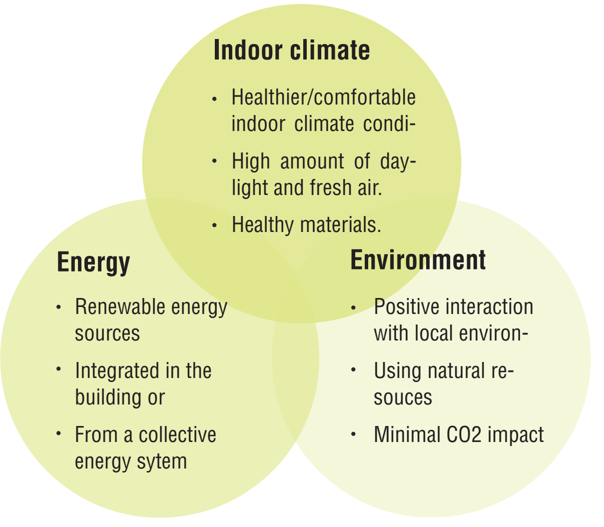


Figure 05, The three spheres active house concept

Sustainable statement

In 1987,The UN Commission produced the famous Brundtland Report. The report set out the goal that "Sustainable development seeks to meet the needs and aspirations of the present without compromising the ability to meet those of the future." [WCED 1987, page 34]. The emphasis was on creating sustainable alternatives to energy production and consumption of materials so as to avoid depleting the world's resources and destroying the environment. Figure 04 illustrates the traditional three spheres of sustainability.

In Denmark, the oil crisis in1973 had led to a new focus on minimizing heat consumption in residential buildings. And subsequent study of residential buildings revealed they are responsible for 30 % of total Danish energy consumption. Efforts to reduce this consumption have resulted in the development of a new residential building, the low energy house. [Larsen, 2011]

In this thesis, two low-energy housing concepts are discussed, known as passive and active. The aim of this project is to develop dwellings that are both sustainable and can also provide residents with a highly satisfying indoor climate.

The passive house is designed to reduce heat consumption, but it can also lead to unpleasant overheating during the summer. The active house concept, in contrast, takes a holistic approach, taking into consideration the total effect of a building's design and construction on the environment, energy consumption, indoor climate and social aspects, see figure 05. The active house concept, therefore, is focused not only on reducing energy and heat consumption within the house, but also on leaving a positive foot print on this world by being self-sufficient.

The technical and architectural features are also simultaneously being developed into a coherent house, with both active and passive strategies applied. The focus is on the future inhabitant of the house and the surrounding context. This concept will therefore be applied in designing a new proposal for a denser dwelling as an alternative to the single-family house in Denmark.

The project's focus on sustainability concerns not only the actual housing units, but also the creation of an urban layout that can encourage a more sustainable way of living. Studies have shown that if people are living in dense cities, with all the required daily activities close-by, the use of cars are minimized. The goal here is thus to remove cars from the urban plan and instead create and improve bicycling, walking pathways and green spaces where residents can interact.

Figure 06, Daily functions in the area

Day care centre
Kindergarten
Municipal
Upper secori-
dary education

Shopping
Cultural activities
Fitnees
Groceries

Figure 07, Green areas

Figure 08, Public transportation options

★ Site's location

500 meter pr. circle

Location

The chosen location for this project is located in the municipality of Høje Taastrup, located in northeast Zealand, 20 kilometres west of the Danish capital Copenhagen. The municipality, containing a central town and outlying suburban communities, has a population of 33.000 [Høje Taastrup kommune 2016].

In the decade from 1965-75 the municipality expanded with new residential areas dominated by block of flats, terrace- and single-family houses. The block of flats constitute for almost half of the residential buildings in the whole municipality. Today, the town contains several local shopping centres including the well known 'City 2' mall, cultural activities, schools, childcare facilities, different varieties of grocery shops and both train and bus stations linking it with Copenhagen and nearby towns. [denstoredanske.dk, 2014]

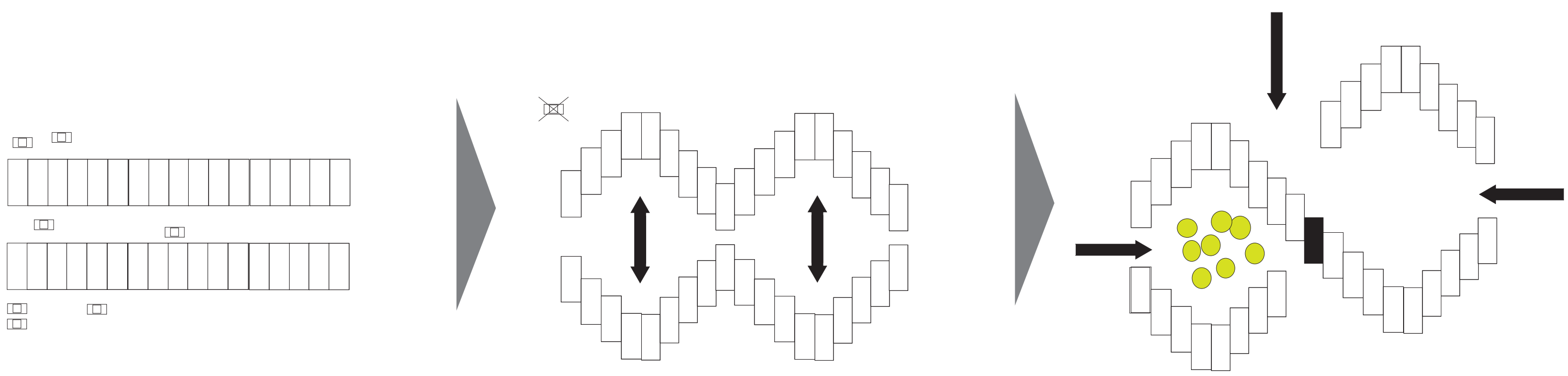
The municipality is focused on converting former building areas to new attractive green urban dwellings. The site was previously occupied by a centre with grocery boutiques erected in the 1960s to supply the surrounding residential areas. In the last few years, however, the older shopping centre has been outcompeted by new large shopping malls. The municipality has developed a new district plan for developing low-rise buildings on the site: terraced houses up to three floors with pointing roof. The new urban area should provide the future residents with green space for leisure pursuits and social gatherings, internal small pathway systems and the area should be designed to contribute to existing neighbourhood community. [Lokalplan 1.74, 2012]

The site is located in the middle of a large residential area consisting of blocks of flats, terraced housing and single-family homes. The area with three-story block of flats is placed to the north of the site which has large green spaces and playground facilities for the children. There are single-storey single family houses to the south of the site. The surrounding low-rise buildings ensure a rich amount of solar exposure and no disturbing shadow casting on the site.

The area is exposed to only light windy weather; the existing buildings provide some wind buffer to the site. The urban context contains large green spaces, trees, and is a bicycle-friendly neighbourhood with many families with young children. The site is in close proximity to several schools, kindergartens and day-care centres. The large City 2 shopping mall is 600 meters away, and Taastrup's main shopping street is just 10 minutes' walk. Figures 06-08 illustrates distances from the site to green areas, schools, shopping areas and public transportation, each ring represent 500 meters.

Urban Landscape

Concept



Step 1 - Traditionel layout of terraced house urban area

The traditional layout of terraced houses from the 1920s was to place all the houses in a straight line. The houses formed a long narrow street, where the cars dominated the townscape.

The goal for the current project is to create an alternative townscape where people and nature are the predominant feature; hence, all the cars are removed and placed in a basement garage underneath the site.

Step 2 - Creating distances between houses

The former straight row of houses are now dislocated, allowing the houses to create positive spaces between them and some distance so as to enhance a feeling of privacy between the dwellings.

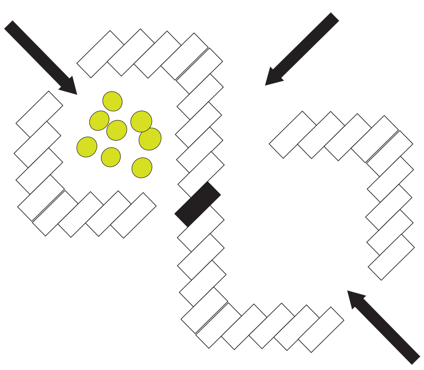
The spaces become courtyards and green spaces that connect the houses and provide the residents a venue for casual interaction.

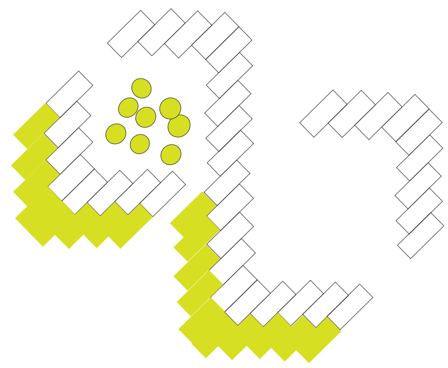
Step 3 - Access to the area and creating a centered community house

The lines of dislocated houses are pushed from each other to create space between them. A community house is placed in the middle of the centred line and becomes a gatehouse that connects the two courtyards and the basement garage.

The residents are encouraged to meet by placing the exit from the basement garage in the gatehouse.

Figure 09, Urban concept, life between buildings





Step 4 - Orientated the houses to face south west - solar cells

All houses are oriented towards the southwest in order to enhance sunlight exposure in the morning and evening.

Step 5 - Giving the landscape height difference

The lines of houses are given different heights due to sun exposure, variety in the landscape and creating an entrance to the basement garage from the main road.

The highest line is towards the north and the lowest to the south. The height difference allows increased sunlight exposure from the southwest into the lines to the north.

Step 6 - Diversity between houses, gardens and without gardens

The urban landscape is given a degree of diversity by placing two different types of terraced houses on the site, with two different lots sizes. There are houses which are designed as townhouses without gardens, but with a close connection to the surrounding courtyards.

The second option is a terraced house with a garden. None of the gardens have the same size, since they are framed by the boundaries of the site. The courtyards are given different atmospheres.

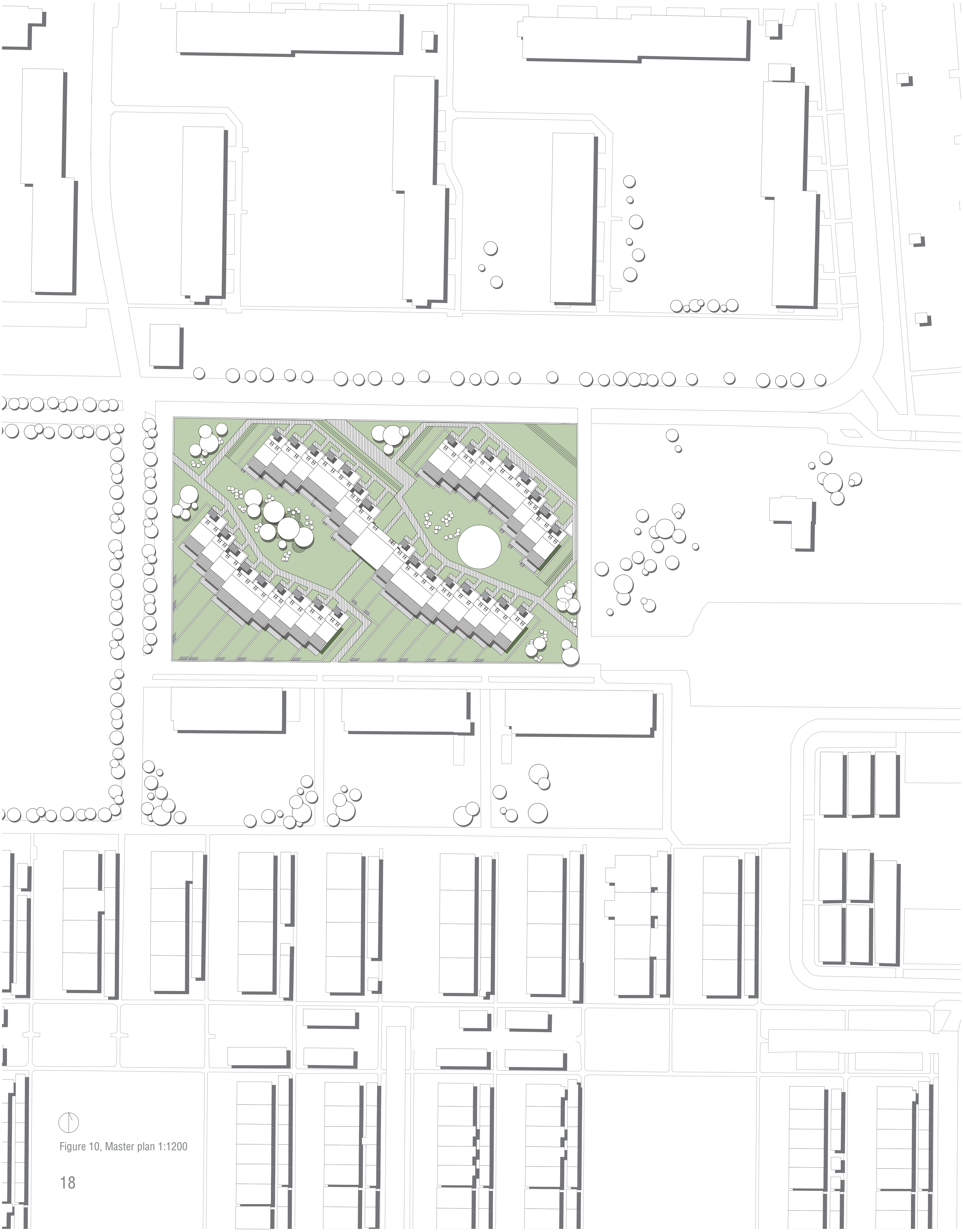


Figure 10, Master plan 1:1200

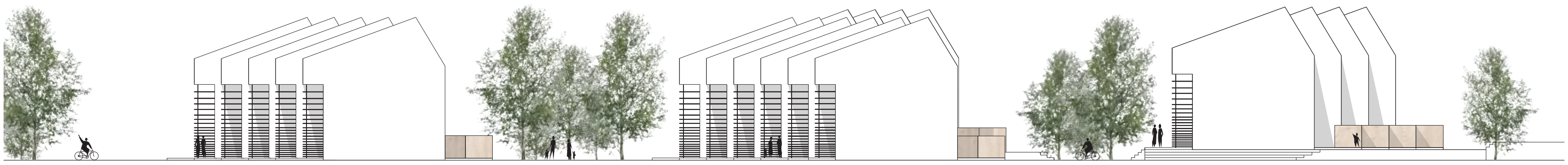


Figure 11, Elevation East 1:500

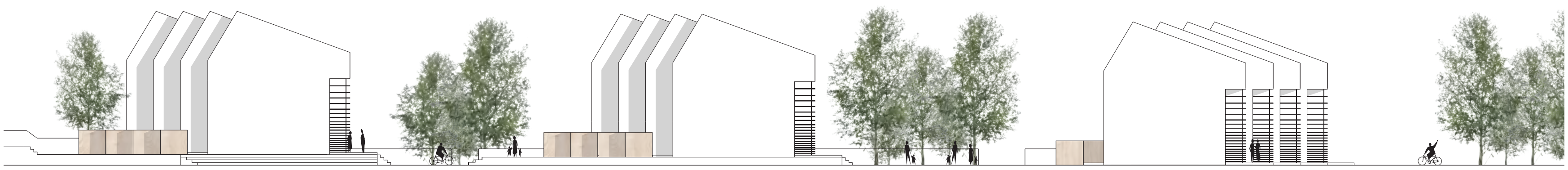


Figure 12, Elevation West 1:500

Location - relation to the context and residents

Today in Denmark, the terraced house, also called row house, has been reborn. This house type is a dominating feature among newly built urban spaces. Unfortunately, many of the new projects have fallen back to the strict functionalism of the 1930s, with the houses placed in a straight line and no real consideration given to the spaces between the buildings.

As Jan Gehl describes in his famous book Life between Buildings, the spaces between the buildings is where social life is, and buildings can shape this life if they are thoughtfully placed on a site.

The project described in this thesis has thus been inspired by the low and dense residential housing areas of the 1960s and 1970s, where the houses were displaced in order to embrace the surrounding nature. One of the famous projects is Sjølundsparken, just outside the town of Elsinore, built in 1978. [Case study 4 page 110]

Today there remain few large buildings plots; hence, this project has been placed on a site in a large Danish town to show that it is possible to create urban spaces where the buildings create the landscape and provide the residents with the kind of spaces that can encourage social activities.

The designed dwellings have been placed on an uneven line that creates positives spaces between them. The functional rigid system from the surrounding contexts is broken by the creation of a new urban space with rhythm in the placement of the buildings, see figure 10.

The site is connected to the surroundings by having created a connection between the present pathways in the area with the pathways in the new urban space. The houses are placed so that they open up towards the main road to the north and create an inviting atmosphere.

All of the cars have been removed from the urban landscape and placed in a basement garage underneath the site, where there is parking for 92 cars. The entrance to the parking facilities is placed to north of the site, with a connection to the main street in order to create an easy transition from the road to the parking facility.

Figure 13, Master plan 1:600

Figure 14, Elevation North-east 1:500

Figure 15, Elevation south-west 1:500

The urban infrastructure and diversity

The urban plan has been designed specifically to improve the conditions for using bicycles, walking and to create spaces that are safe for children to play. The pathways follow the bending line of the buildings and are connected to each house. See figure 13.

To make bicycles more visible, all the houses have been equipped with a bicycle shed that directly adjoins the pathways. The trees are placed close to the pathways so that they function as wind sheltering and also enhance the enclosed spaces.

The pathways are designed to accommodate the changing needs of daily life, being wide enough to drive a car and unload it during e.g. moving. The pathways go through the community house, which links the two courtyards together as a gatehouse. The gatehouse is enhanced by the placement of the parking garage basement exit at the house.

The courtyards and green spaces between the houses is where the social life of the community unfolds. Children can play on the pathways with their bicycles, the youngest children can play in the courtyards where the parents can easily monitor them, and the older children can choose more remote places, e.g. the green triangle placed to the north with a view over the main road, where there could be football goals.

The urban spaces are created by placing 32 terraced houses and one community house on the site, which gives a 20 % building percentage on the ground. The floor area to site ratio (FAR) is 53%. If the site had been used for traditional, detached single-family houses, the FAR would have been about 22%.

There are two different types of terraced houses: two- and three-bedrooms, able to accommodate a variety of family combinations. The two different types of houses have been placed randomly in order to create more diversity. The diversity revealed clearly on the rhythm of the facades, see figures 14-15. The harmony of the facades is enhanced by using the same materials for all the houses. The materials are used to create a link between the houses and as a simple but strong architectural expression.

The urban plan is developed in order to accommodate the different preferences people can have as concerns gardens. Some peoples prefer a garden and others not. To amplify the diversity, 15 of the houses have no garden but instead large terraces on the ground surround by bushes. The remaining houses each have their own gardens. All the gardens are equipped with a shed that can house garden tools and other implements.

Figure 16, Courtyard

Figure 17, solar cells

Figure 18, zinc plates on roof

Figure 19, Grey tiles on floor inside the houses

Figure 20, Light concrete on the facades

Figure 21, Thermal treated pine on the sheds and community house's facades

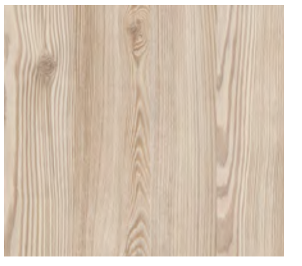


Figure 22, floor inside the houses

Materials

The materials have been chosen according to their sustainability and architectural qualities. To minimize the carbon dioxide emissions during the construction of the projects, all the materials are from Danish manufacturers.

The houses are based on a simplified construction principle which is reflects in the choice of materials. The Swedish architect Sverre Fehn has been a great inspiration for designing concrete buildings that are also elegant and beautiful by combining different materials, wood and concrete. The wood provides a warmth and soft contrast to the harder, functional concrete.

The buildings' envelope is a reinforced concrete sandwich element. The slender concrete slabs are used on both the exterior and interior surfaces. The concrete walls are treated with a warm light colour, see figure 20. The windows in the envelope have wooden frames. The wood texture is reused on the terraced flooring and on wood surfaces. To accommodate the goal of designing a sustainable housing project, all the wood used in the houses and surrounding details is pine, a common Scandinavian species. The pine wood is treated using a sustainable method, thermal wood treatment. The pine is treated so that it has a light warm texture, see figure 21. The flooring inside the house on the first and second floors is of light oak wooden boards. Oak is a durable species and often used for interior wooden surfaces. The southwest roof is covered by black mono crystalline solar cells.

The solar cell panels are integrated into the roof so that they create a wholesome architectural expression, see figure 16. The rest of the roof surface is covered by anthracite coloured zinc plates. The zinc plates have the same dimensions as the solar cells panels. The plates are 100% reusable, have a low productions energy consumption and are maintenance free. The dark roof creates a strong contrast to the light concrete surfaces and wooden details. [Zink, cradle to cradle, 2016]


Figure 23, Courtyard connected to the main road,looking from west

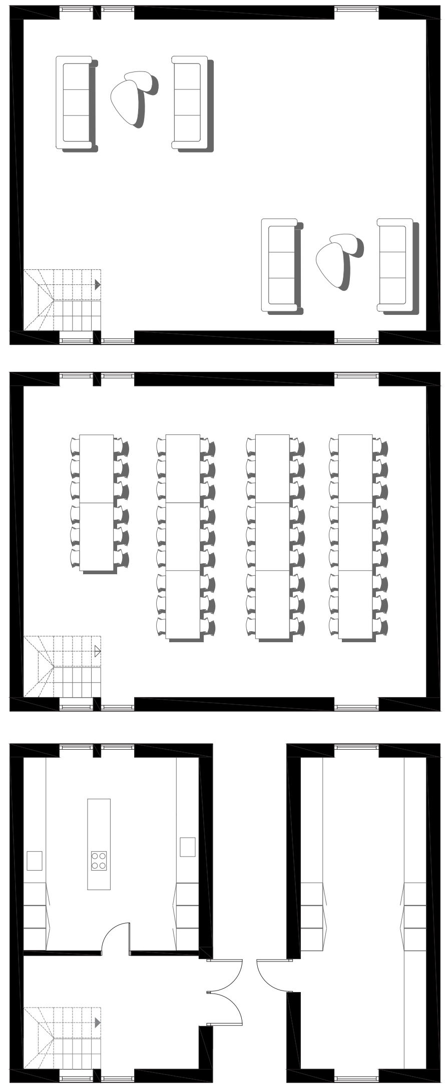


Figure 24, Plan layout for community house, 1:200

Courtyards

The two courtyards in the urban landscape have been given different functions and atmospheres. The first courtyard is placed in the northern end; it has a strong connection to the main road, which is accentuated by creating a large inventing opening. The main pathways lead the visitors from the public main street into a semi-public area.

This courtyard is designed to facilitate social activities. The courtyard contains removable wooden benches with tables, a fire ring, a playground area and direct connection to the community house, see figure 23.The community house provides the residents with a place to meet all year round and links the two courtyards together.

The house has three floors. To distinguish the building from the others, the facade is covered by narrow wooden boards and long vertical lines emphasis by the black window ribbons. The roof is covered by anthracite coloured zinc plates and solar cells on the south-west sloop of the roof.

The ground floor of the community house has a large kitchen with a stair going down to the basement garage and upwards to the two other floors and a workshop area in the other side; at the workshop, the residents can meet up and fix up their bicycles and other things.

On the first and second floor are two large rooms that can accommodate large parties, social gatherings and indoor playing area for children during the winter. The house is the social focal point for the whole urban layout. See figure 24.


Figure 25, Courtyard toward south, looing in from west

Courtyards

The pathway through the community house leads to a more private courtyard. This courtyard has been given a more tranquil atmosphere. The residue earth from the excavation of basement garage will be used here to create small hilltops where people can lie underneath the birch trees surrounded by fruit bushes and wild plants. See figure 25.

Birch trees are planted between the houses to provide residents with both privacy and shading from the sun during the summer. The birch trees are often seen in the Danish nature and are a deciduous plant. The advantage of using deciduous plants is that they change colour all year round and the leaves fall off during the winter, providing the houses with greater sun exposure.

The birch tree has a white slender tree trunk and long, slender hanging branches. The leaves are small and plentiful during the spring and summer. The branches are so delicate that they move when the wind blows.

Both courtyards have fruit bushes and wild flowers, and the hedges around the houses are the typical Danish beech. The beech hedge is also a deciduous plant and gives a variety of colours.

To create a gradual transition from the greenery in the urban landscape and the houses, the gables at the end of the line of houses are covered by ivy, which during the autumn change to a scarlet colour.

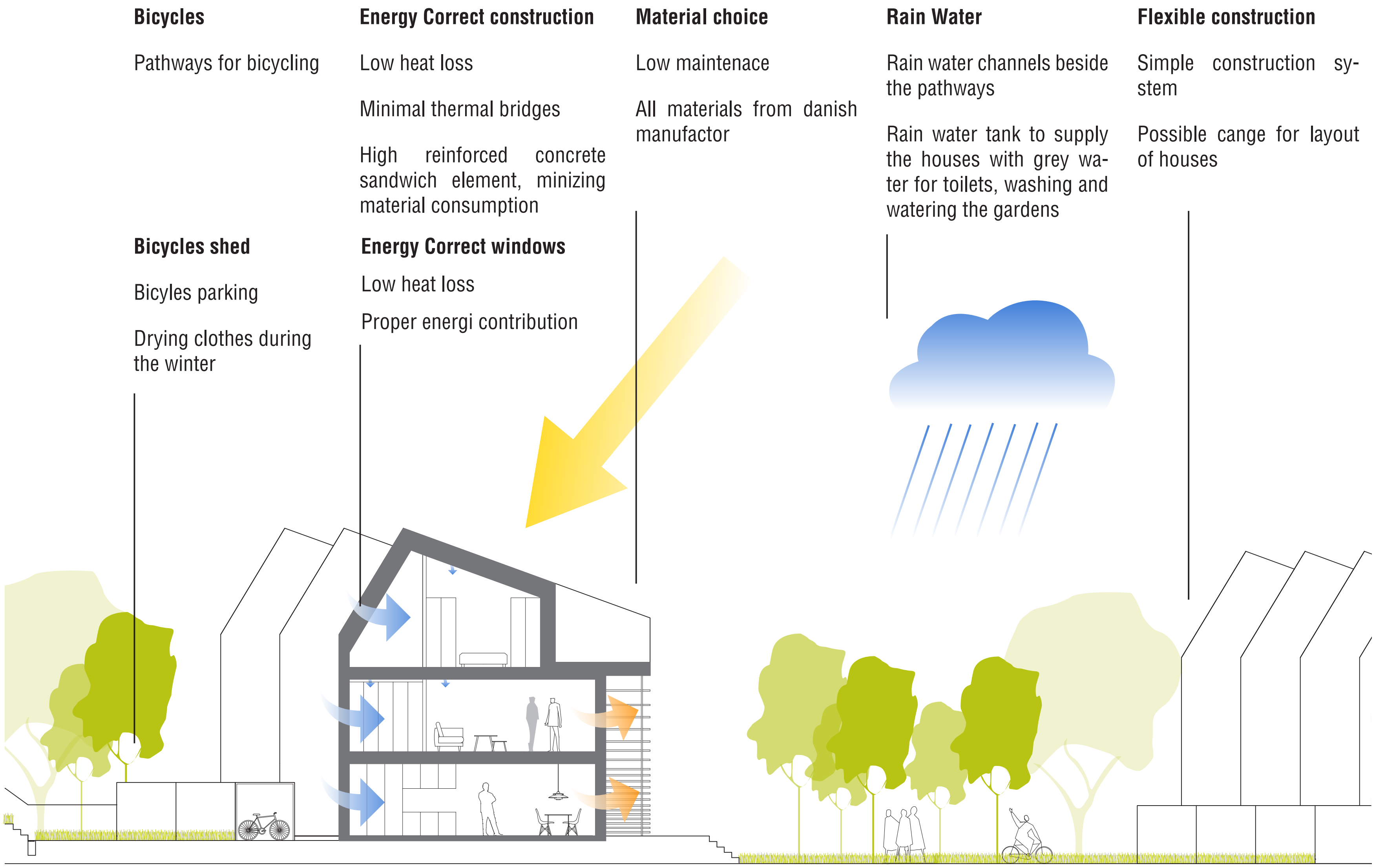


Figure 26, Sustainable initiatives scale 1:200

Sustainable initiatives

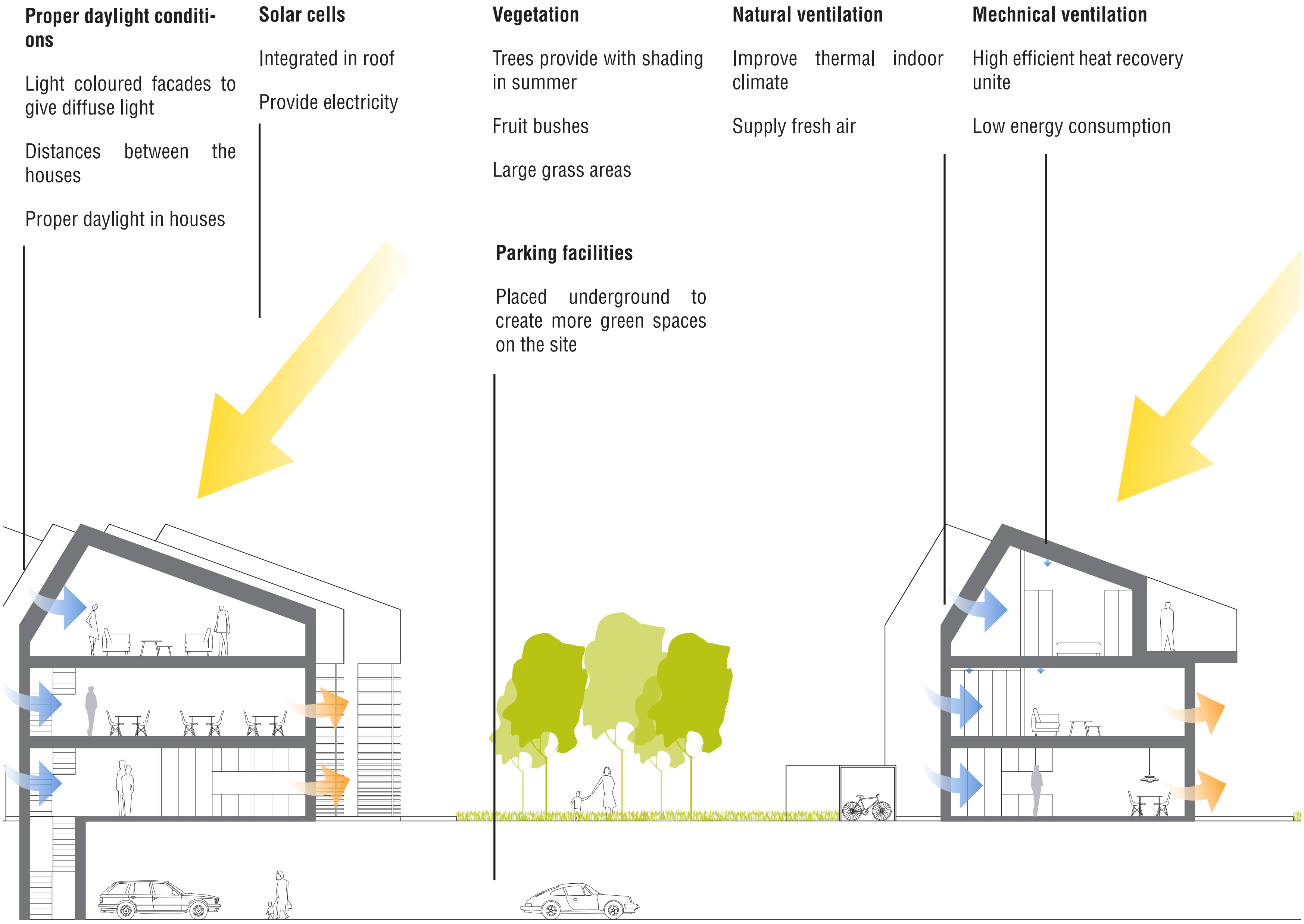
This project has been inspired largely by the active house concept, focusing as it did on the holistic design to create a pleasant indoor climate, low energy consumption and attention to the environment. However, I am also inspired by the book Cradle to Cradle written by M. Braungart and W. Mcdonough. Their suggestion to building houses that have the same quality as a cherry tree is inspiring.

Their idea is that a cherry tree nourishes itself by using the natural resources to the fullest and provides its surroundings with food and shelter. The tree becomes a part of the circle of life. After it has died, it is recycled to earth and becomes a place for a new plant to grow. Figure 26 shows all the sustainable initiatives in this project, both in the urban layout and in the design of the houses [Braungart & McDonough 2009].

The architecture is designed to provide energy-saving solutions. The bicycle sheds are designed with a room to dry clothes all year round, as clothes dryers are extremely energy-consuming home appliances.

The solar-panelled roofs produce electricity all year round. The envelope has a great influence on the energy and heat consumption of a house. Therefore, the construction ensures that the components in the house have no or minimal heat loss.

The materials have been chosen based on the ability to be recycled, low maintenance



and minimum carbon dioxide emissions during production, transportation to the site and construction. All the materials are from a Danish manufacturer. The houses exploit the sun for passive heating and provide efficient sunlight during the day to lower the need for electrical lighting. The rooms in the houses are designed to exploit natural ventilation.

The community houses can be equipped with large freezers which residents can use to minimize the need for large freezers in the homes. By placing a large number of freezers together, energy consumption in the houses is minimized. The community house's south-west roof is covered in solar cells.

The urban layout is designed to accommodate the Danish local diversion of water (LAR) principle. Large underground tanks are placed to harvest the rainwater. The LAR principle is applied in order to reduce the pressure on the sewer system. The rainwater can be used to water gardens, wash clothes and flush toilets.

There are large green areas where residents can grow vegetables and fruits for their own consumption. All the sustainable initiatives are incorporated in the design to provide future residents with the best possible tools to live a sustainable life style.

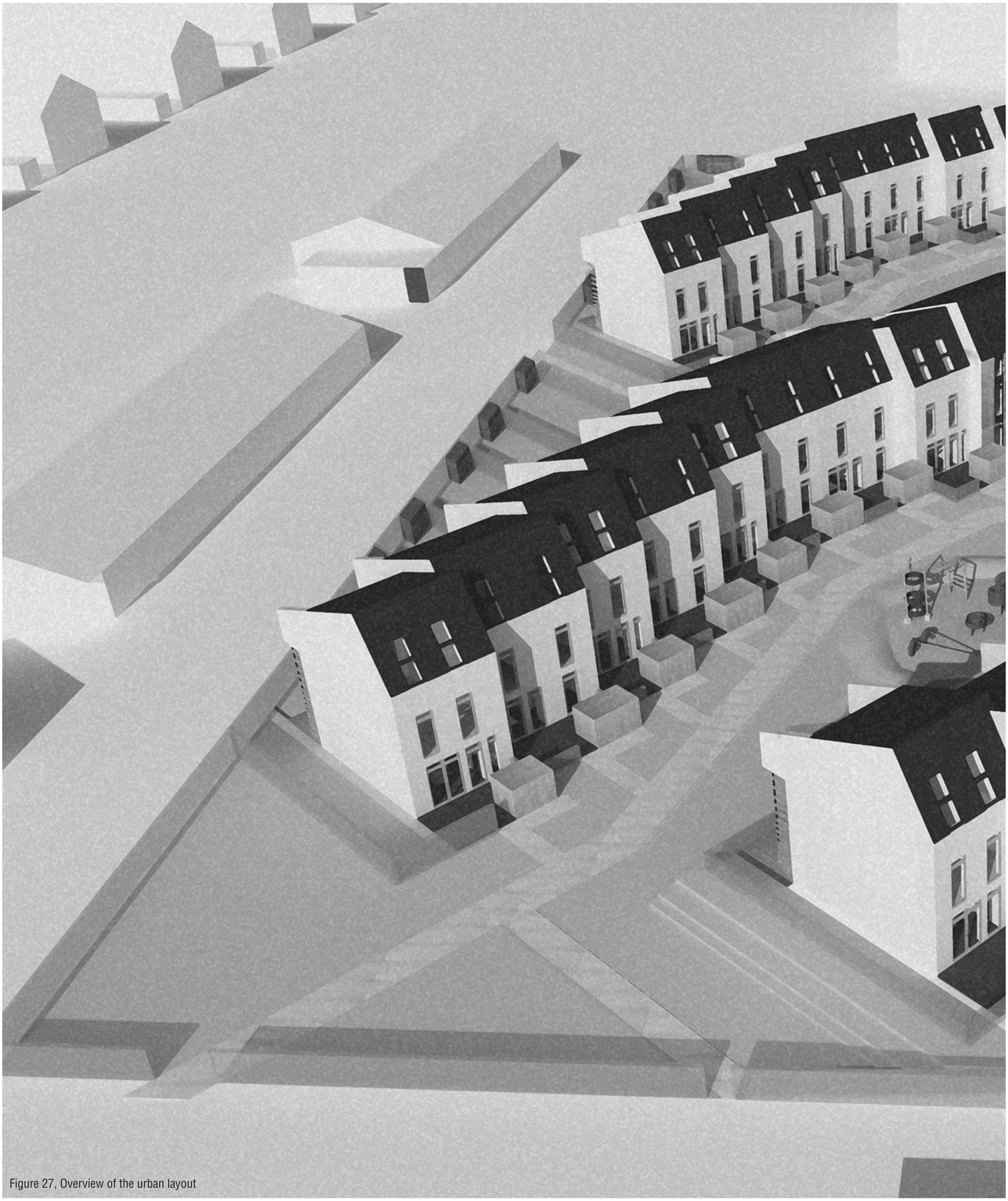
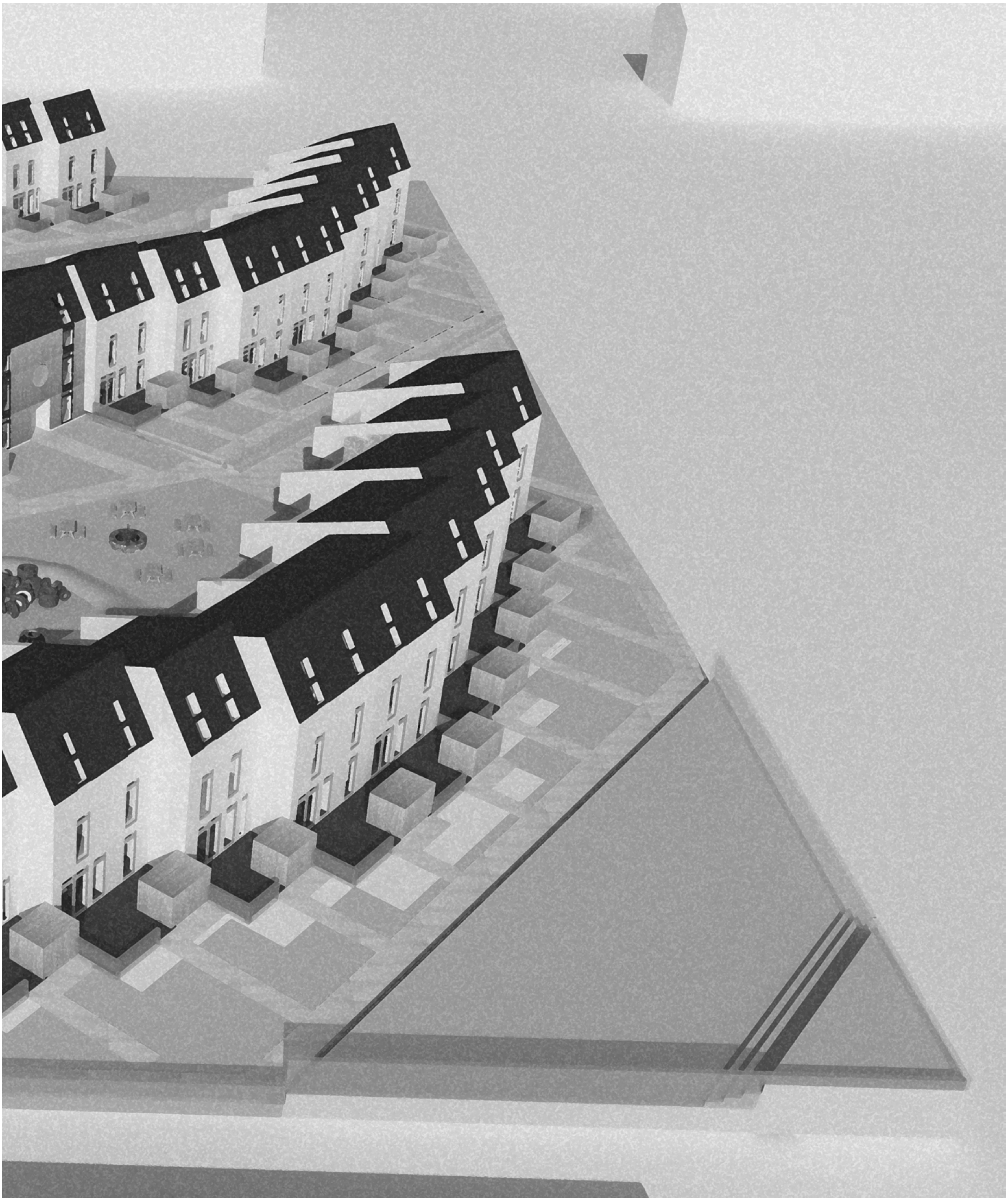
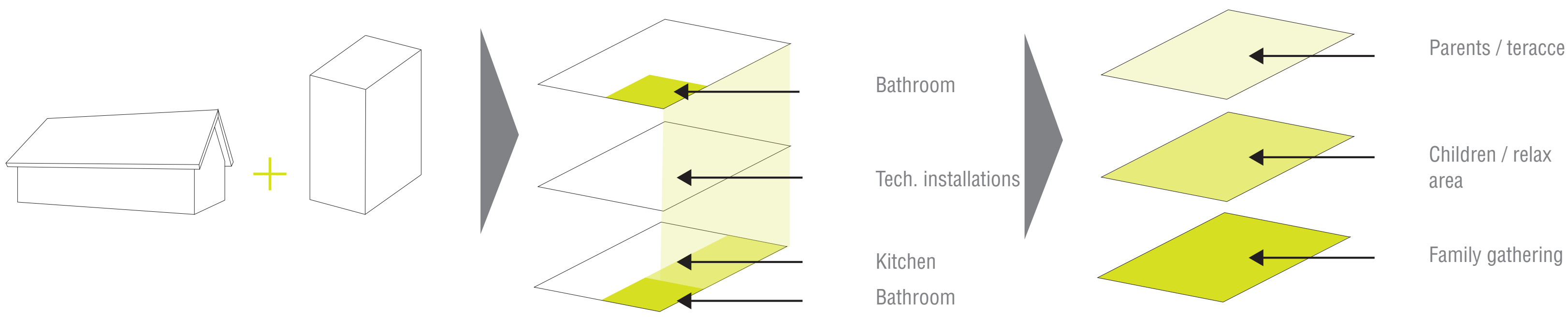


Figure 27, Overview of the urban layout



The houses

Concept



Step 1 - Merging the single-family house with the modern terraced house

Step 2 - Plan concept for technical layout

Step 3 - Plan concept for functions

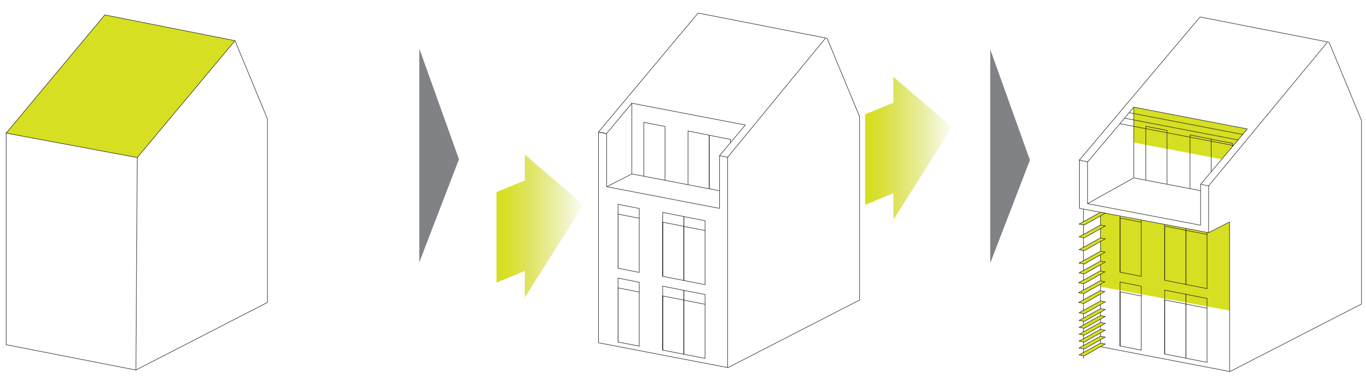
The traditional single-family house, with point roof and single-floor high building is merged with the modern squared terraced house, which has a flat roof and up to three floors high.

The technical requirements for the house are placed above each other to create a simple, coherent solution for all the installations.

The sewage, water and ventilation pipes are all placed on one side of the house.

The house is divided into three zones; the first zone is the family area, with kitchen and dining room; the second zone contains the children's bedrooms and a large open room which can become a play area or an extra living room and the third zone is the parents' floor with master bedroom and bathroom.

Figure 28, Concept of the houses



Step 4 - Solar cells - shape of roof

Step 5 - Orientation, ventilation and heating strategy

Step 6 - Solar shading integrated in the envelope

The roof of the house is inspired by the pointed roof from the single-family house. The roof is shaped so that it can have a large area of solar panels; therefore, the sloop to the south has the largest area.

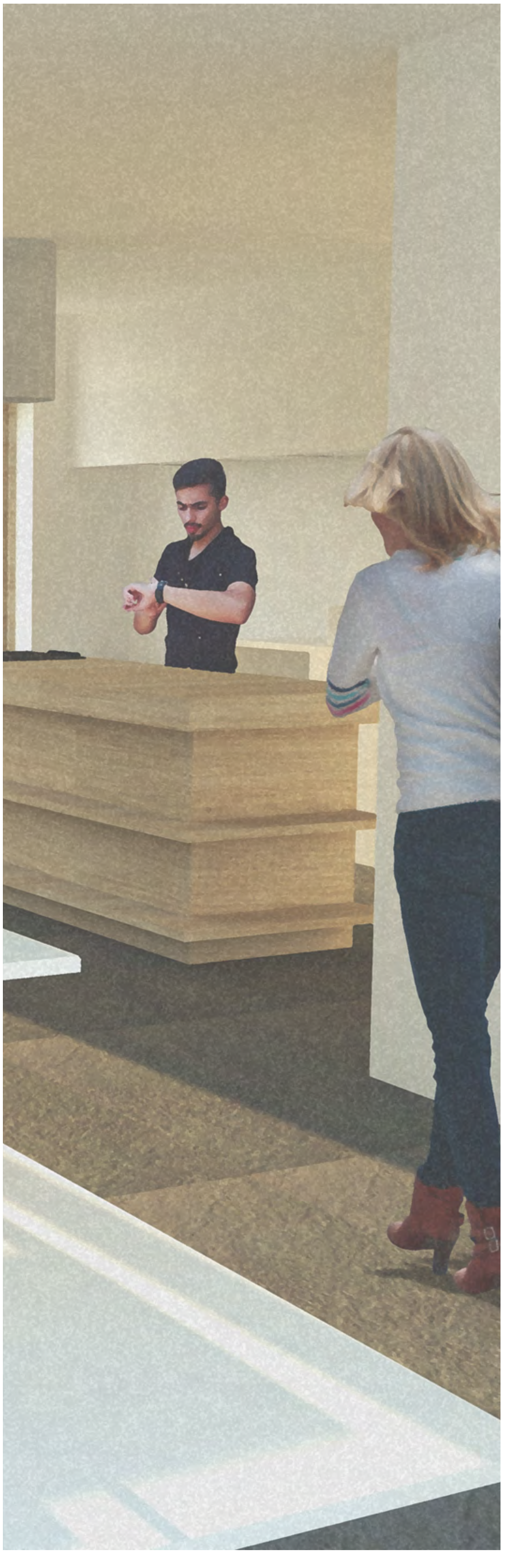
The houses are oriented and designed to exploit the natural resources from the sun and wind. The houses are facing south west with large in order to exploit the heat from the sun during the winter and proper daylight during the whole year.

The building is dimensioned so that it can exploit the natural ventilation strategies, both cross and singled-sided.

The solar shading is integrated in the design of the envelope. A large terrace on the second floor is pushed out so that it can be permanently integrated shading for the windows on the first floor during the summer.

Options have been designed so that deciduous plants can be used as shading elements during the summer by placing wires over the windows where plants such as ivy can grow.

Figure 29, Ground floor from north east



Main data		
Be10		
Energy frame	19,5	kWh/m2 per year
Numbers of the house		
Netto floor area	143	m2
Gross floor area	165	m2
Roof terrace	20,5	m2
Amount window area/gross floor area	24,8	%
Rooms in the house		
Bathroom	2	
Bedrooms	3/4	
Living room	3	
Installations		
Compact aggregat	Yes	
Demand controlled ventilation	Yes	
Heat recovery effectivity	87 %	
Solar cells roof/railing	38,6 m2	

Figure 30, Main data for the 3 bedroom

Terraced house with 3 bedrooms

The urban spaces consist of two types of terraced houses; a three- and a two-bedroom. Both types of house are designed on the same principal for plan layout, constructional and facade design. The three-bedroom model, 165m2, is designed for families with children who are attracted to the suburban lifestyle in a single-family house.

This house can offer all the qualities of a single family home and provide the residents with a sustainable dwelling placed in a social shaped urban landscape. The dwelling's design is based on the active house concept, with a focus on integrating the technical and architectural qualities from the very beginning to give families a home with pleasant indoor climate, renewable energy resources and an environmental positive footprint. The pleasant indoor climate has been achieved using passive strategies; e.g., placing all the bedrooms facing northeast so as to minimize overheating exposure, while the living room faces southwest to exploit the passive heating from the sun. All the rooms have windows that provide a high quality of daylight without overexposure to the surrounding contexts. There is integrated solar shading in the envelope with the use of overhang, vegetation and external solar shading curtains. The rooms are dimensioned so as to exploit the natural ventilation principles in cross and singled-sided fashion. [see explanation on page 91]

The materials have been carefully selected for their sustainable qualities and to achieve a pleasant atmosphere in the dwellings. The materials are concrete and wood, which supplement each other very well. The wood softens the hard, light-coloured concrete and gives a more human ambiance to the homes, see figure 29. All the integrated features and details in the house are emphasized using a light oak wood material e.g. the stairs, integrated tables, etc. The energy frame of the dwelling meets the 2020 class standards for low-energy class construction by having an annual consumption on 19.5 kWh/m2 year. The house's electrical consumption is covered by the solar cells on the roof and railing on the 2nd floor. The consumption of domestic heated water can be covered by an air-to-water heat pump system. The house is heated with a combination of water carried underfloor heating and a high efficiency heat recovery unit installed in the ventilation system. See figure 30.

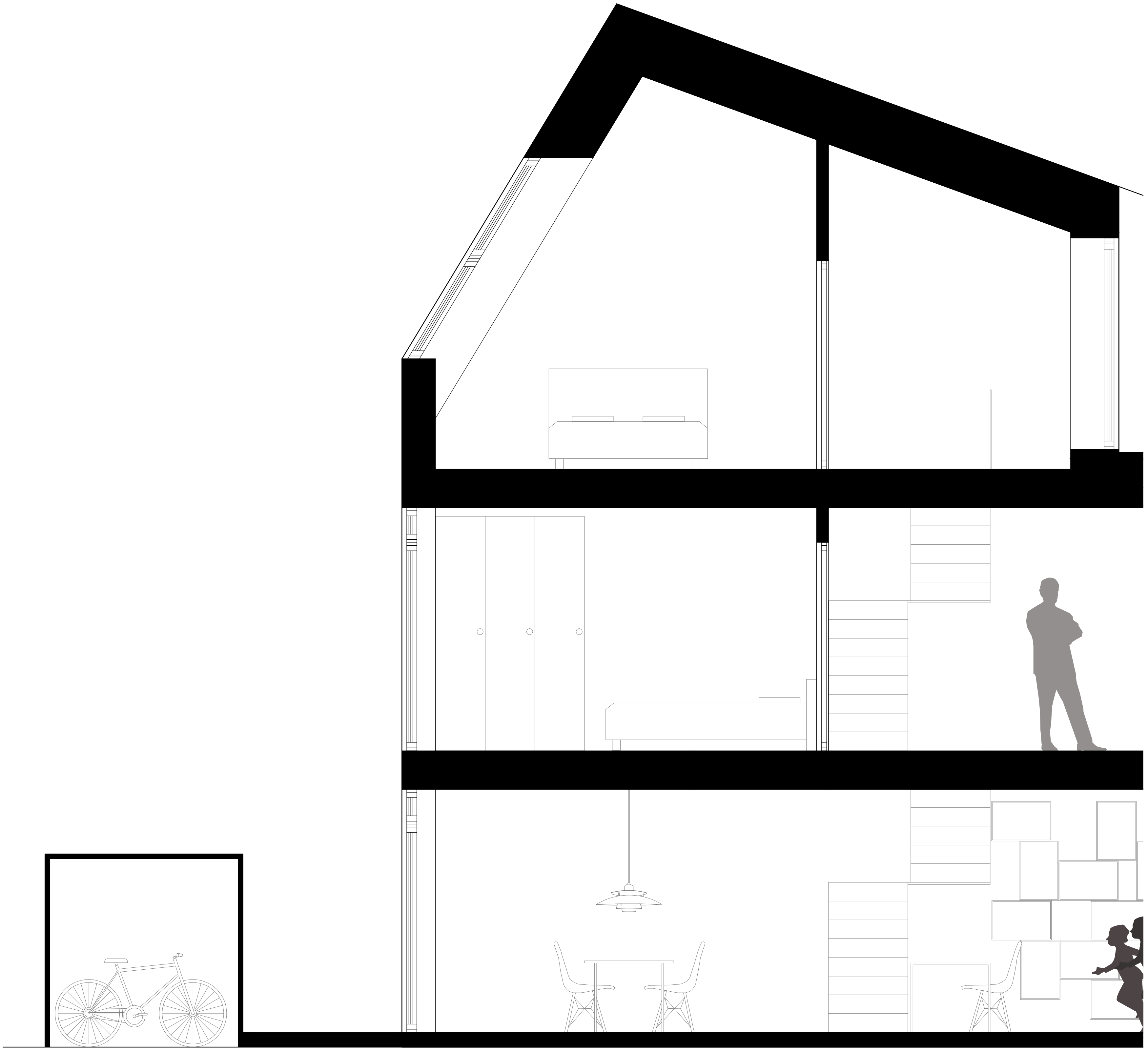
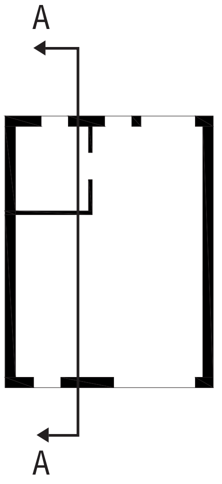
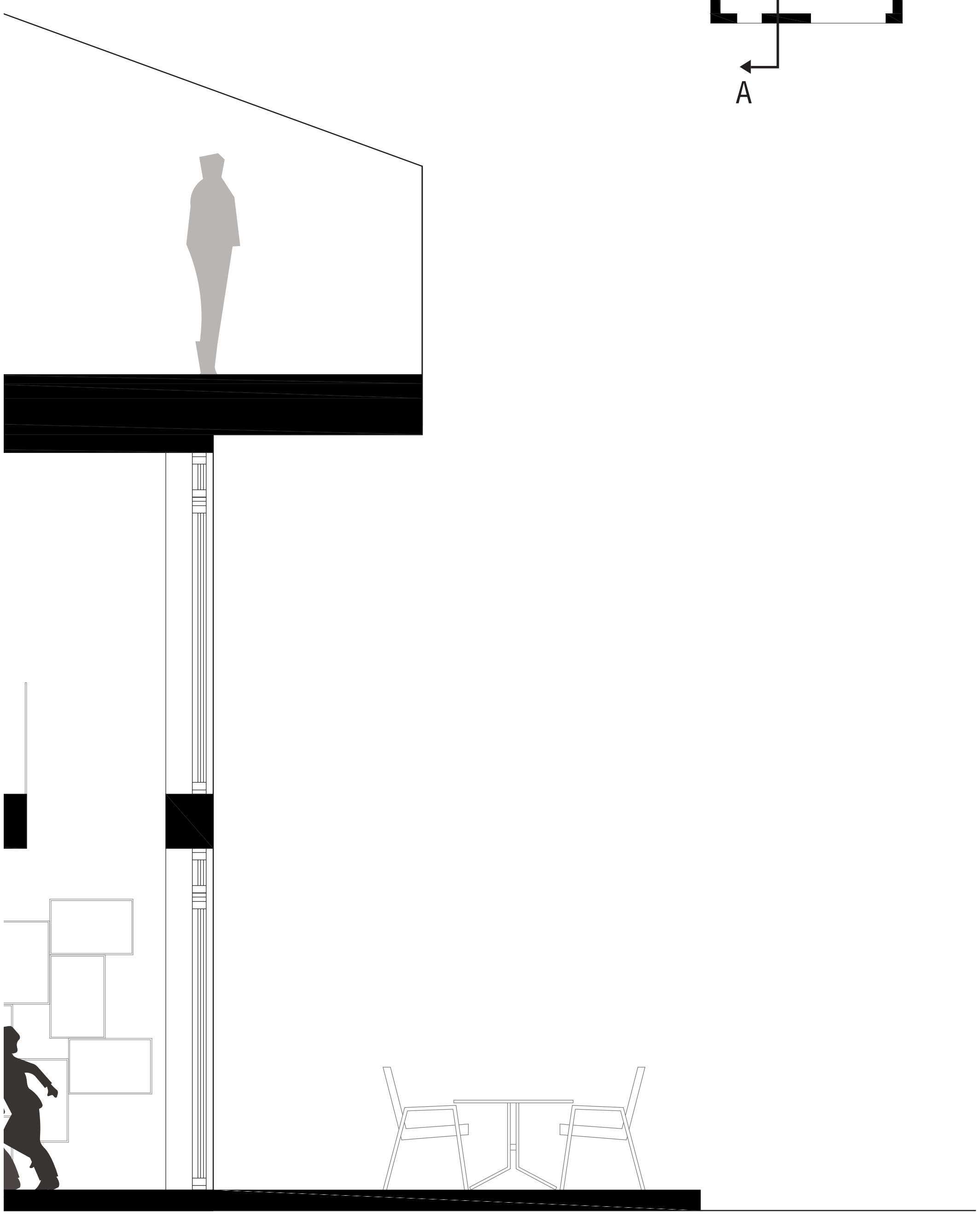


Figure 31 , Sectoin A-A, of the three bedroom house, 1:50





The flow in the house

The entrance to the house faces north-west, with a direct connection to the pathways in the courtyards. The main door leads directly into a large open space with a direct view to a slender green garden through large tall windows. Two tall windows are placed to the north-east, providing the family with sunlight in the morning. The free standing stairway is made of light oak, which filters the light through the room. The stairway become a multifunctional furniture: it can store books on shelves on one side, and on the other side a long slender table treated in the same material.

The children can sit underneath the stairs and do their homework while the parents prepare dinner in the kitchen. The room invites a social togetherness as a family. A large section of tall windows is placed in the south-west wall, all the windows on the ground floor are actually doors which open up to a large terrace with slender wooden slender boards. The transition from the inside to the outside is smooth, making the ground floor appear even larger with the opening of all the doors to the garden in the summer.

An aperture in the upper (first) floor cast light down to the ground floor, thereby connecting the two floors. The stairs from the ground floor leads up to the first floor which is designed for children. The windows in the bedrooms give the children a view to the activity in the courtyards, and by placing the windows all the way down to the floor level, even the smallest children sit in front of them and look out. The bedrooms are connected to a great open space with a large section of windows that allow a wide view outside. This room can become whatever the family desires: a large play room, a living room where the family can relax together or a combination of both.

The stairs leads up to a second floor, which is the parents' area. The space in front of the stairs is directly connected to a grand roof terrace by a large section of windows placed to the south-west. The space could be used as an office or an extra living room. The master bedroom and bathroom faces north-east and has a skylight, which give the rooms' additional lighting deep into the spaces. See figure 31.

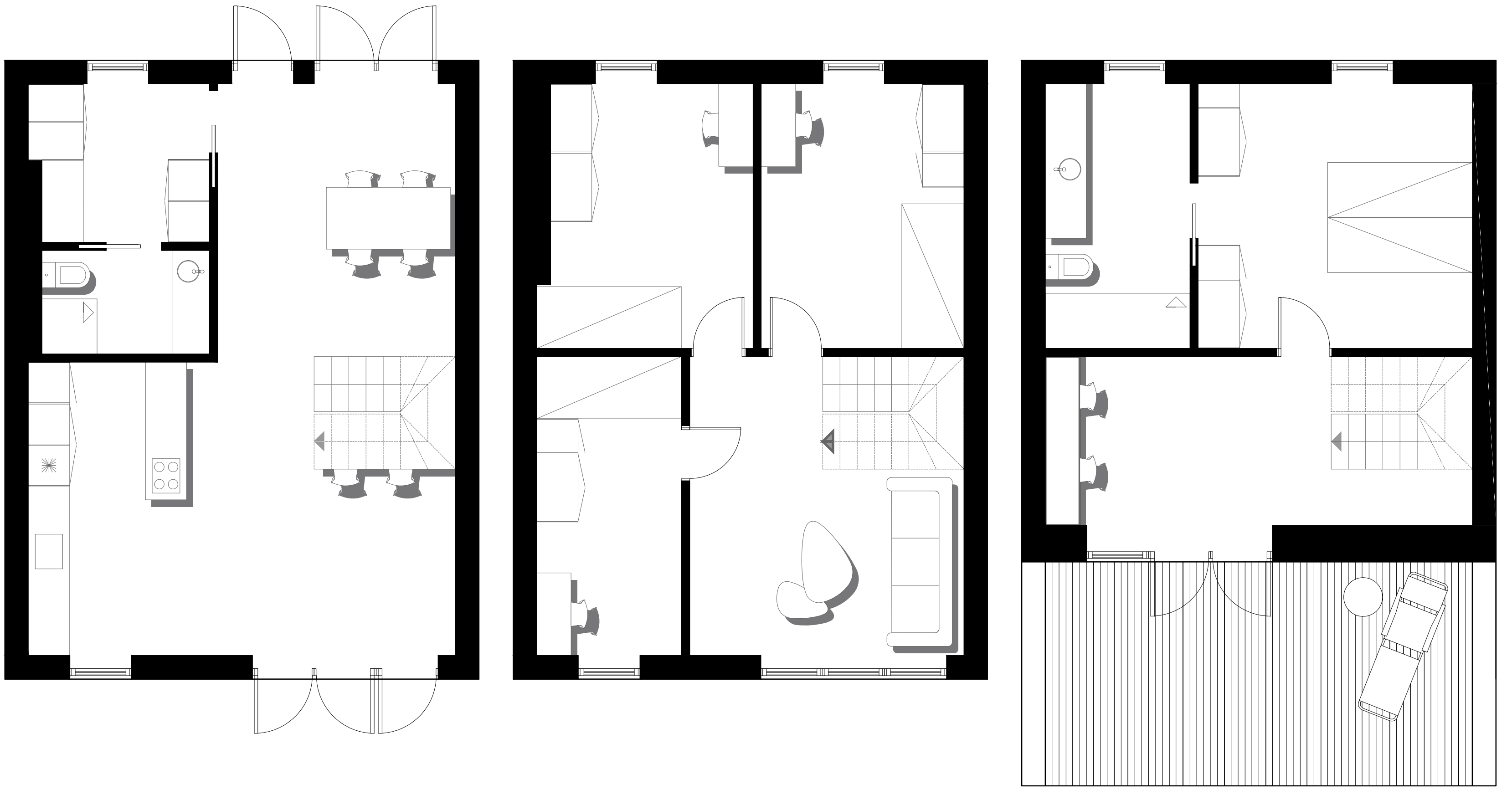


Figure 32, plan layout of 3 bedroom house, 1:100

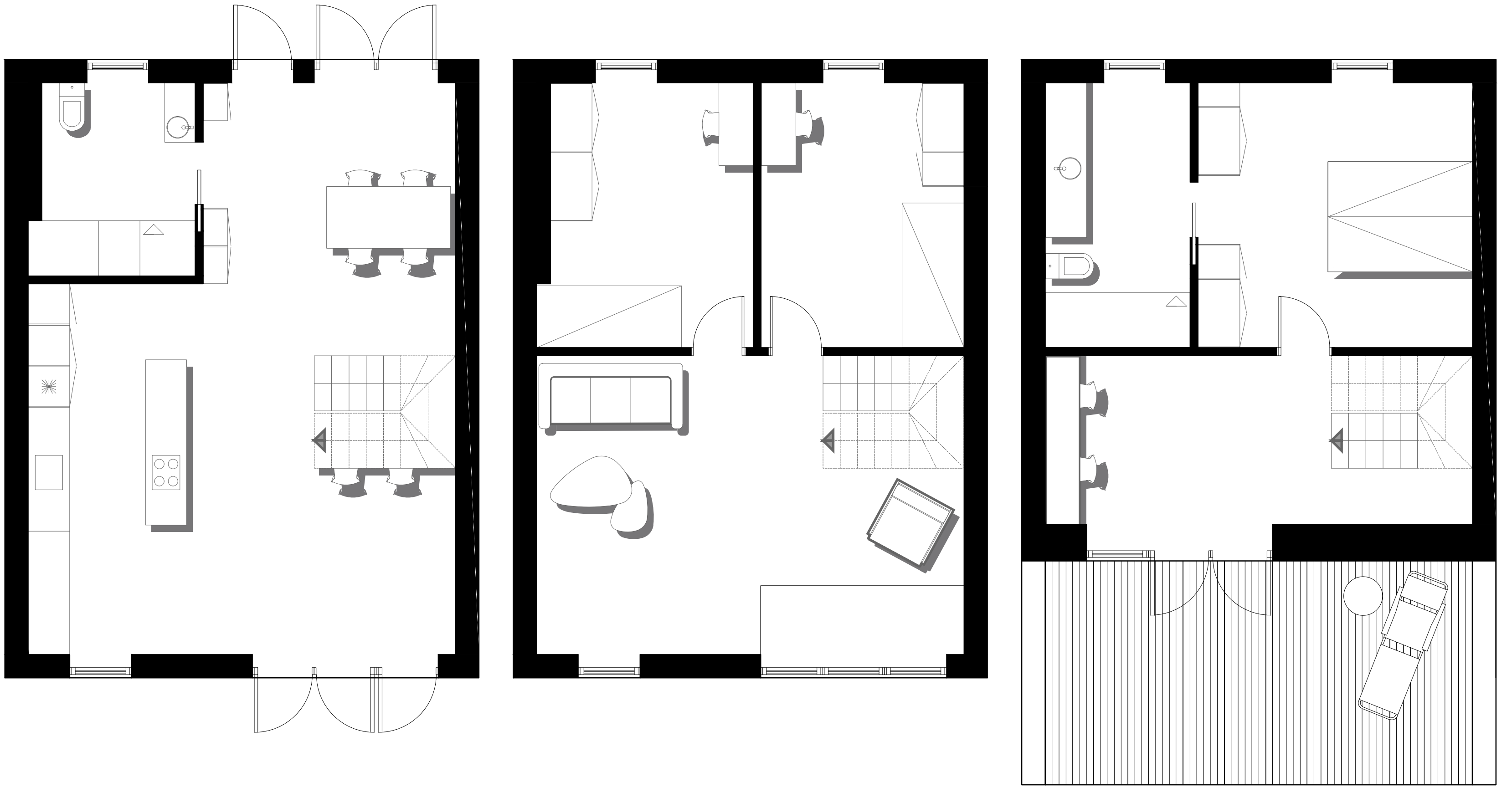


Figure 33, Adaptable floor plan layout for 3 bedroom house, 1:100

The ability to adapt

The layout of the house has been developed as an alternative to the traditional terraced house with locked plan drawings and strict walls systems. This alternative terraced house type is designed to be flexible and can be adapted for the future and changing size or needs of a family.

The construction system is based on a simple discs and plates system. The exterior wall between the houses is the load-bearing element, and the decks between the floors consist of a long concrete slab which lies on the load-bearing walls. [further construction explained on page 66-67]

There are no load-bearing interior walls, which allow residents the possibility to tear down interior walls and build new ones as they see fit. The space to the left and right of the stairs can be used as a living room or dining area. They are almost the same size and therefore allow a wider range of interior layouts.

The ground floor is treated with practical, dark grey tiles that are easy to clean when the children run through the room with dirty shoes on. The guest bathroom and scullery (utility/laundry room) have been joined together into a single room. This bathroom is designed to be multifunctional, containing all the utility installations, washing machine, dryer and guest/children's bathroom. The kitchen is placed with access to the garden.

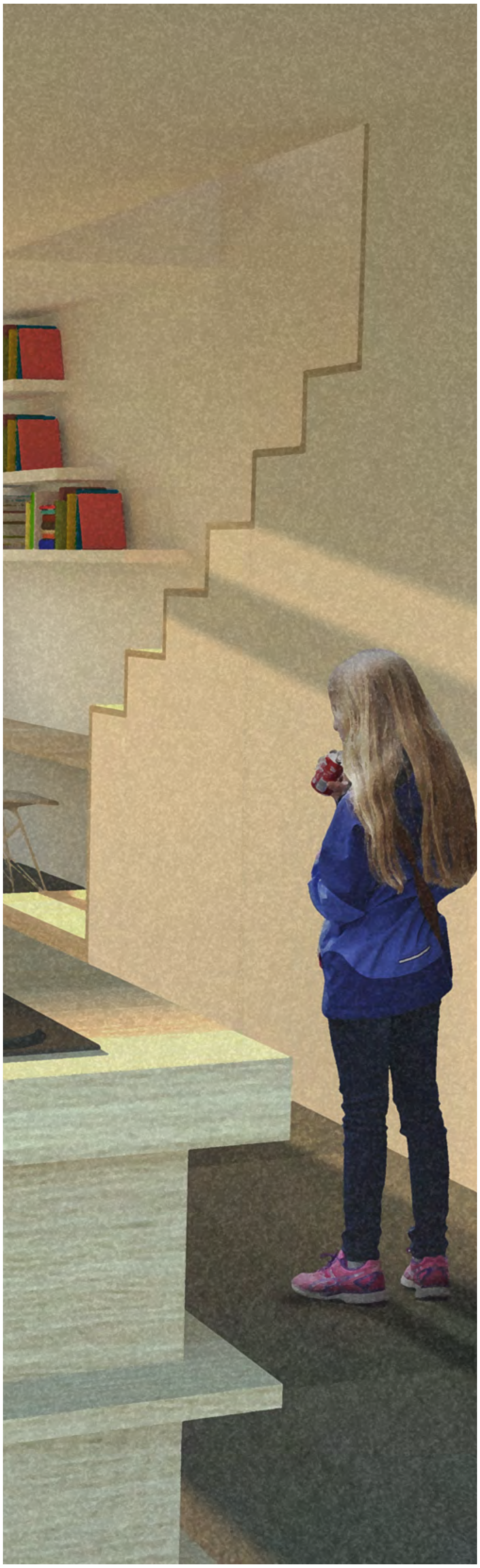
The two upper floors, being more private and intimate than the active ground floor, have a warmth light oak wooden flooring. The floor materials indicate the use of the different floors and set the atmosphere in the spaces. See figure 32.

Over time, a family can expand with having more children. This house can accommodate such changes by altering the layout of the first floor (where children's bedrooms are located). The first floor can thus be transformed from having two bedrooms to three. There will still be space for a small living/family room. The rooms can adapt to the families needs. See figure 33.

The ground floor can also be slightly altered to accommodate the family's wishes for a closed off entrance to the house, with a scullery/utility room and separate bathroom. This house type shows that it is possible to develop dwellings that can change over time and accommodate the families' changing needs.

Figure 34, View from the first floor living room

Figure 35, View from the kitchen on ground floor



Main data		
Be10		
Energy frame	19,0	kWh/m2 per year
Numbers of the house		
Netto floor area	111	m2
Gross floor area	129	m2
Roof terrace	16	m2
Amount window area/gross floor area	26,4	%
Rooms in the house		
Bathroom	2	
Bedrooms	2/3	
Living room	2	
Installations		
Compact aggregat	Yes	
Demand controlled ventilation	Yes	
Heat recovery effectivity	87	%
Solar cells roof/railing	29,5	m2

Figure 36, Main data for 2 bedroom house

Two-bedroom terraced house

The second terraced house is a smaller, the two-bedroom type, with an area of 129 m2. The house is designed for families and couples who are attracted to a town house feeling in a dense city. This house offers a family a slender open planned terrace house with plenty of space and close connection to the urban landscape.

The dwelling design is based on the active house concept, as described in the three-bedroom terraced house. The energy consumption meets the standards set in the 2020 Danish building regulations with an energy frame on19.0 kWh/m2 per year. See figure 36.

The aim of these two house types is to create a dwelling that can adapt to the different needs of the family, but which is also designed with integrated multifunctional furniture. Hence, the stairway is no longer just a stair; it could become a table, a shelf, a wardrobe and so on.

The interior design has been treated with the same architectural consideration as the exterior, and each floor has been given a frame from which the family can arrange the layout of their furniture and décor, thus allowing them to express their personal aesthetic tastes. See figure 35.

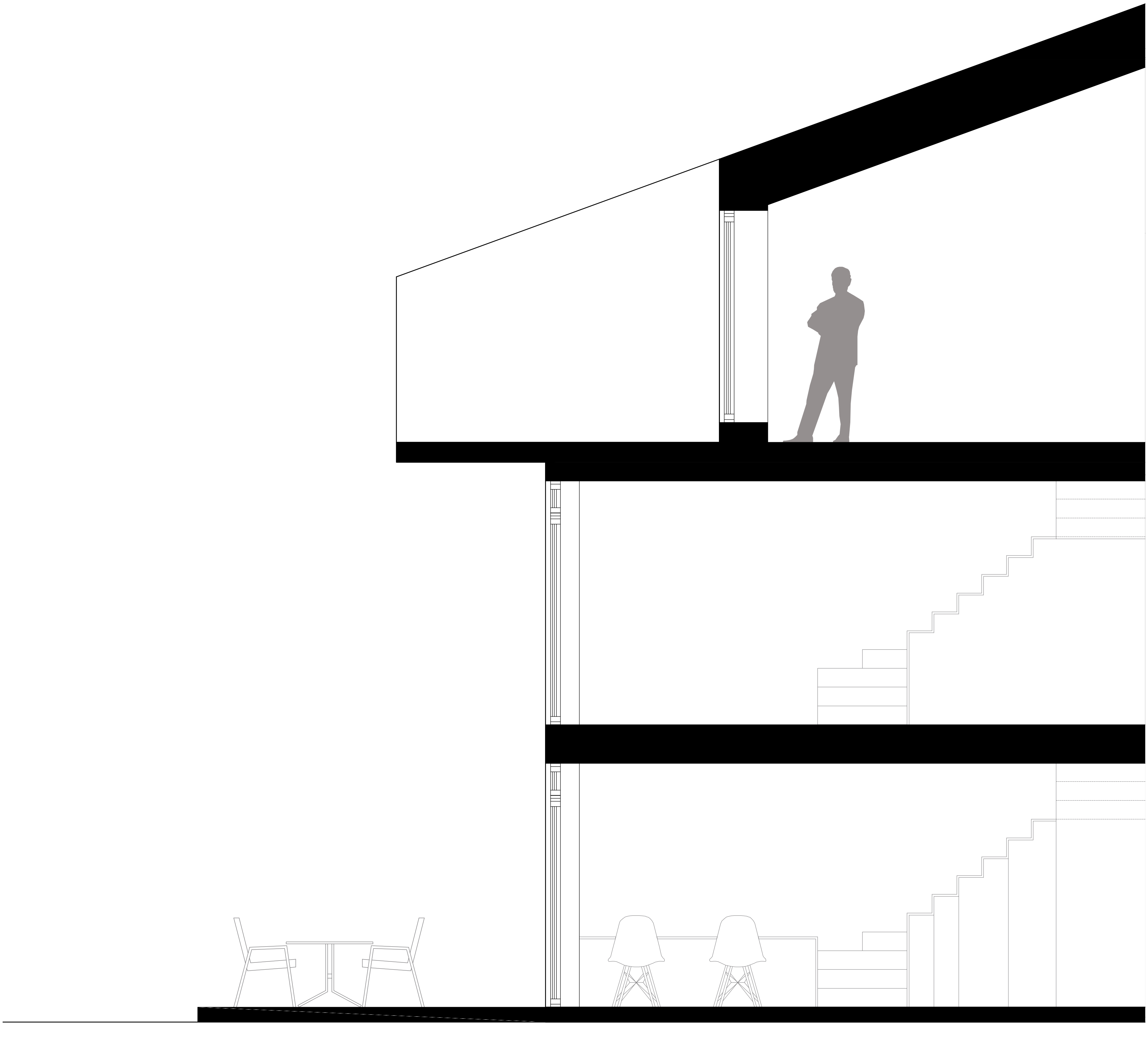
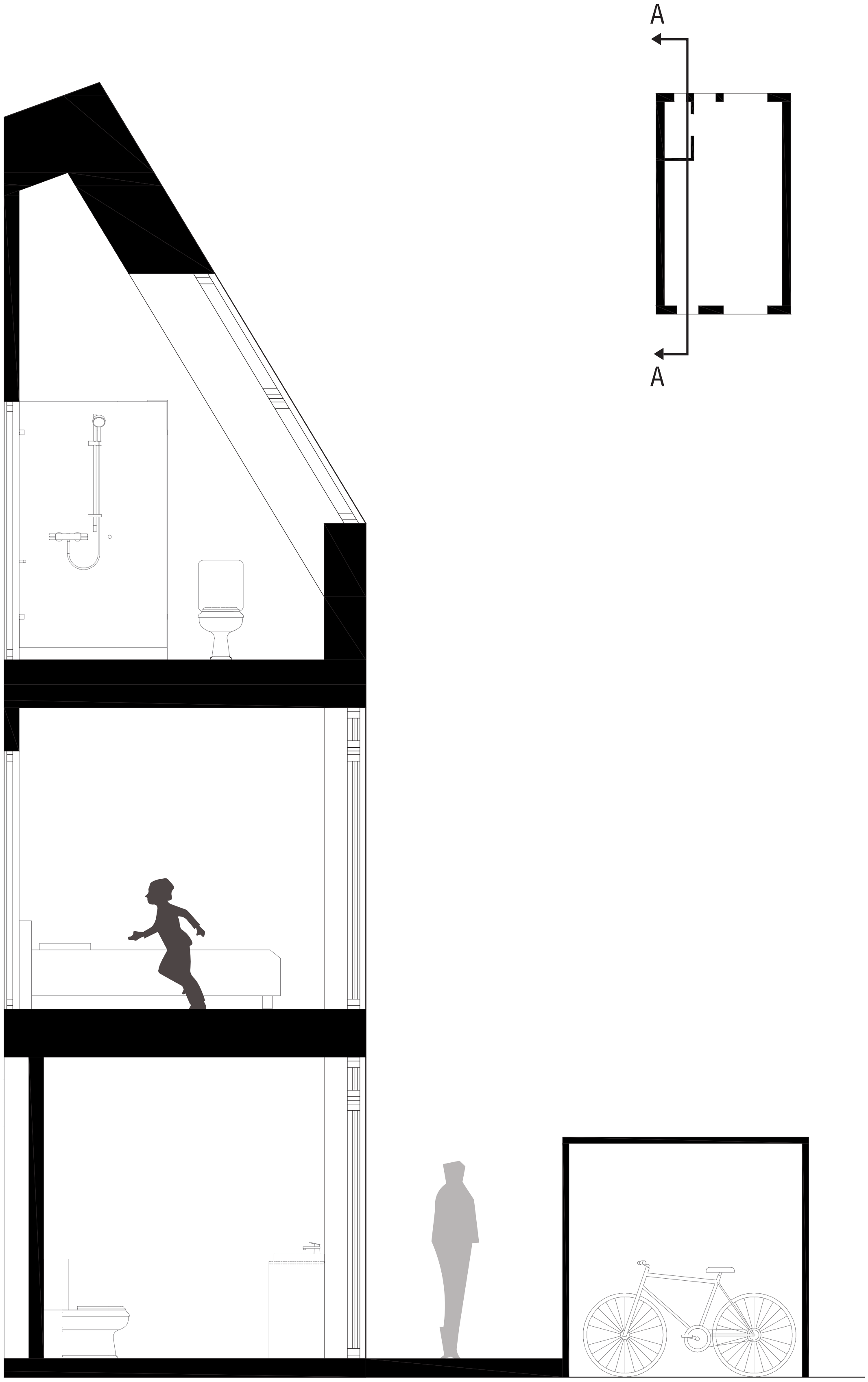


Figure 37, Section A-A, of the two bedroom house 1:50

The flow in the house



The entrance of the house, facing north-east, is connected directly to the pathways in the courtyards. The main door leads directly into a large open space, with a direct view through a large high section of windows to a slender green garden. Two tall windows are placed facing the north-east, thus providing the family with sunlight in the morning. The kitchen is placed directly to the front garden with a terrace linked by a two glass doors.

During the summer months, the family can open the doors wide and enjoy their breakfast on the terrace, with direct connection to a courtyard and green areas. The kitchen has an open floor layout which invites to social gatherings, and it is connected to the entire ground floor room.

The stairway leading to the first floor is multifunctional furniture: the spaces underneath the stairs can be used as a built-in closet, where the family and guest can hang their coats, jackets and store winter and summer clothes. One of the steps from stairway is extended to become a table where children can sit and do their homework in a social context with the rest of the family.

The great section of windows/doors to the south-west leads directly to an outdoor terrace connecting the inside and outside together. All the doors can be wide open, thus creating a feeling of extending the interior room.

The stairway leads directly up to living room, with a beautiful view over the surrounding landscape, and to a children bedroom placed on the north-east side of the house. Following the stairs all the way up to the second floor, there is a grand master bedroom with own bathroom. The master bedroom is directly connected to a 15m2 large open roof terrace with a view over the surrounding landscape. See figure 37.

The terrace has slender wooden floor boards of warm light pine. The wooden boards continue up the external wall facing the south-west, thus creating a folded space that exudes a warm atmosphere.

Figure 38, Plan layout of 2 bedroom house, 1:100

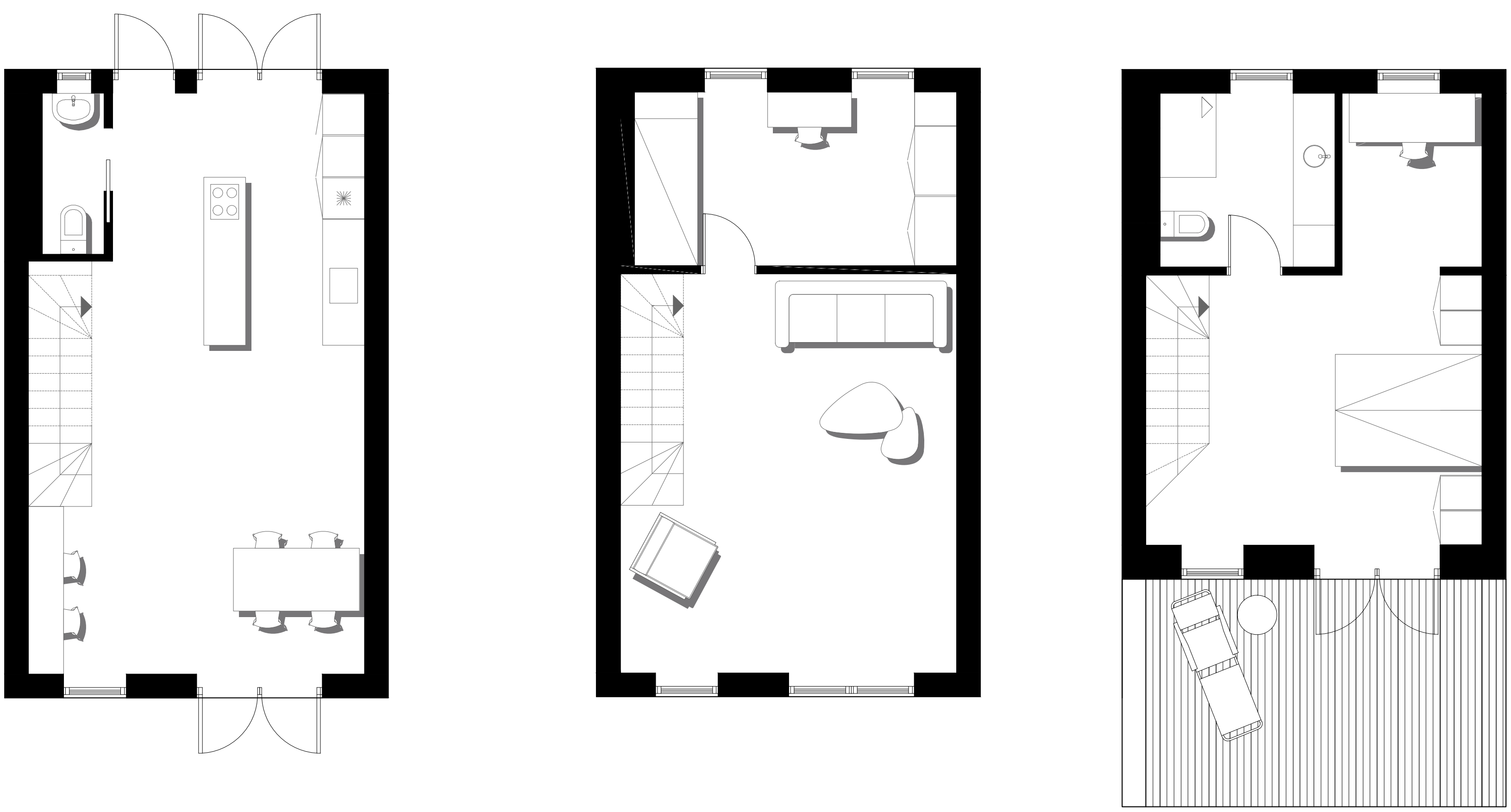


Figure 39, Adaptable plan layout 2 bedroom house, 1:100

The ability to adapt

The two-bedroom terraced house has been designed using the same simple construction principle as described previously. It thus allows the future families to tear down or move the interior walls according to the family's changing needs.

If the couple have no children or they have moved out and no longer need the room on the first floor it can be transformed into an open-spaced solution.

On the second floor, the space beside the bathroom can be rebuilt as an office, a child's bedroom or a walk-in closet.

All families in Denmark are different in how they want to live in a home and how they want to re-shape the interior spaces according to their specific needs and tastes. These houses are designed to adapt to these changing needs and different families over the house's lifespan. See figure 38-39.

Figure 40, View from first floor, living room

Technical details

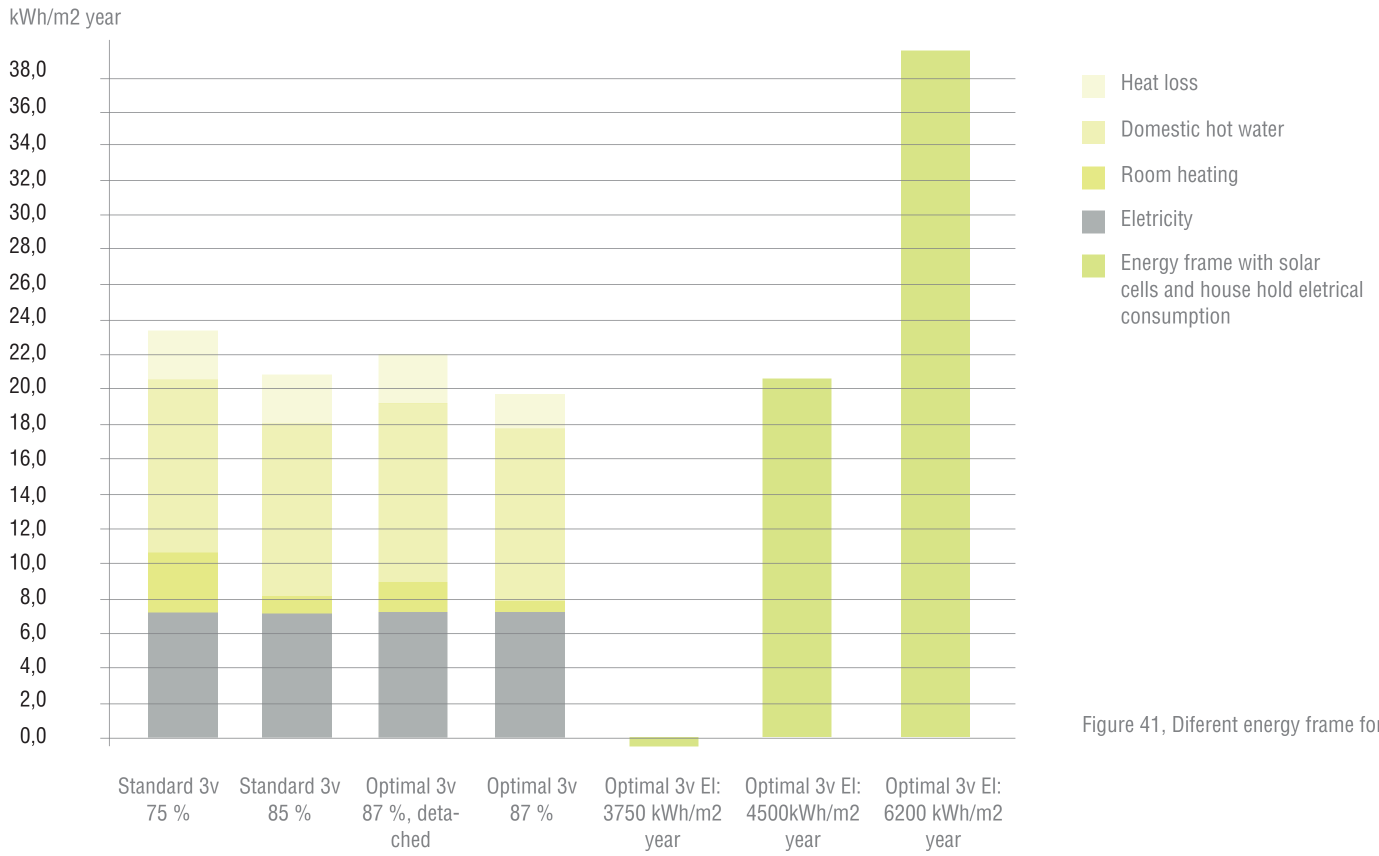


Figure 41, Diferent energy frame for 3 bedroom house

Energy frame

In this chapter, the technical details and calculations are presented and explained. In improving the energy frame and indoor climate, test have been performed to assess how different parameters affect the energy frame and indoor climate. The objective of this project has been to fulfil the building regulations for low energy class according to the 2020 standard. Under these standards, a house's consumption of electricity and heating may not exceed 20 kWh/m2 per year [bygningsreglementet.dk, bygningsklasse 2020, 2016].

The Danish Building Energy program Be10 has been used to document the energy frame for the two types of terraced houses. The two types have been tested in Be10 in two scenarios: a standard with values according to the building regulation for 2020 and an optimised model. Of the two types of terraced houses, the three-bedroom house requires more heating and is therefore used for testing the energy frame, indoor climate and daylight.

The Be10 program uses the following parameters to determine the consumption for domestic buildings: heating, ventilation, cooling and domestic hot water; if the building functions as an office, lighting would also be included. The Danish building regulation seeks to ensure that newly constructed buildings have a sound climate screen by requiring that the dimensioned transmission loss for the climate screen without windows be no higher than 5.7 W/m2 for buildings of three floors or higher. The climate screen is influenced by the U-value for exterior walls, roof and foundation [bygningsreglementet.dk, bygningsklasse 2020, 2016].

To achieve a low dimensioned transmission loss, a dense high insulated concrete sandwich element has been used for the exterior walls. The wall element is slender than traditional sandwich elements, with a U-value on only 0.083 W/m2k for a wall with a thickness on 340mm. The construction principal is explained on page 66-67. Both types of terraced houses have a dimensioned transmission loss of 2.3 W/m2 which meets the standard [bygningsreglementet.dk, bygningsklasse 2020, 2016].

The requirements for windows in 2020 class:

Minimum 0 kWh/m2 year energy contribution

Minimum + 10 kWh/m2 year energy contribution

Glass area is a minimum of 15 % of the floor area

The windows in a building have a great impact on the building's heating requirements. Windows contribute daylight and passive heating from the sun. The windows are made of three-layer energy glass with a U-value of 0,67 W/m2K . The installed skylights have an energy contribution of +22,0 kWh/m2 year.

Both house types fulfill the requirements with a glass to floor ratio of 24.8% for the three-room and 26.4 % for the two-room house. The higher window percentage compensates for a light transmission of 72%. On page 60, the amount of window effect on energy frame and indoor climate is explained [bygningsreglementet.dk, bygningsklasse 2020, 2016].

The 2020 class ventilation requirements are as follows:

Heat recovery unit efficiency of at least 85%

If the house is heated by ventilation air, then additional heating sources are required.

Due to the tests having been performed on low energy houses with only ventilation air as heating sources, the room temperatures were unstable. Therefore, the houses erected in class 2020 must have an additional heating source beyond ventilation air. The terraced houses are equipped with water-carried under-floor heating to ensure a comfortable, even temperature during the heating season [bygningsreglementet.dk, sbi 230, 2016]. The terraced houses are equipped with a heat recovery unit in the ventilation aggregate to recycle the heat from the used air. In the two Be10 'standard values' and 'optimal values', the difference of the windows' U-value and heat recovery efficiency has been tested to assess how these elements affect the energy frame.

The two models have the same:

Climate screen, Amount of windows, People load, Equipment load, Solar cells, shading and ventilation.

The difference lies in the U-value of the windows and the heat recovery unit. By changing the windows' U-value from 0.81 W/m2K to 0.67 W/m2K, the heat requirement decreases by 3.3 % due to reduced transmission loss through the windows. The objective of reaching the 2020 class without an active energy-producing element is not met by only adjusting the windows. See figure 41.

By increasing the heat recovery efficiency from 85% to 87%, the heat requirement is reduced by 5.3%, and the energy frame for the entire building becomes 19.5 kWh/m2 per year, without solar cells or heat pumps. See figure 42. The installations in the house have a great effect on the energy frame. Over time, the installations' efficiency will improve, and they are easier to replace than windows. Therefore, it is recommended that the best possible windows be used, those with a low U-value and a high lighting transmission that will minimize consumption of heating and electricity for illuminating the house.

Project: The Green Village : 3 bedroom Terraced House Optimal values		
Main Data		
Energy frame BR2020		
Energy frame building 2020	19,5	kWh/m2 year
Heating	20,6	kWh/m2 year
El to the building operation	4,0	kWh/m2 year
Over heating in the house	0,0	kWh/m2 year
Output from specific source		
Heating pumps	0,0	kWh/m2 year
solar cells on roof	22,5	kWh/m2 year
solar cells on railing	3,9	kWh/m2 year
Acheiving Zero energy	Energy consumption	Energy frame with solar cells
Energy consumption		
El. consp. low	15	kWh/m2 year
El. consp. average	27	kWh/m2 year
El. consp. high	37	kWh/m2 year
Envelope		
Climate screen	165	m2
Share vindow area/gross floor area	24,8	%
Net area	143	m2
Gross area	165	m2
Transmission loss, climate screen	2,3	W/m2
Construction		
U-values		
Exterior walls	0,083	W/m2K
Roof	0,083	W/m2K
Foundation	0,095	W/m2K
Linie loss -values		
Foundation	0,020	W/mK
Assembly at doors and windows	0,000	W/mK
Windows		
Frame type	wood/alu	
Glass	3 layer glas argon filling	
Uw-value for windows	0,67	W/m2K
Ug-value for windows	0,53	W/m2K
gg - value windows	51	%
LTg value	72	%
Window depth in wall	50	mm
Installations		
Compact aggregate	Yes	
Ventilation rate	0,5	1/h
Heat recovery units	87	%
Distribution water carried heat : underfloor heating in ground floor and bathrom room on 2. floor		

Figure 42, Main data from optimale Be10 model of 3 bedroo house

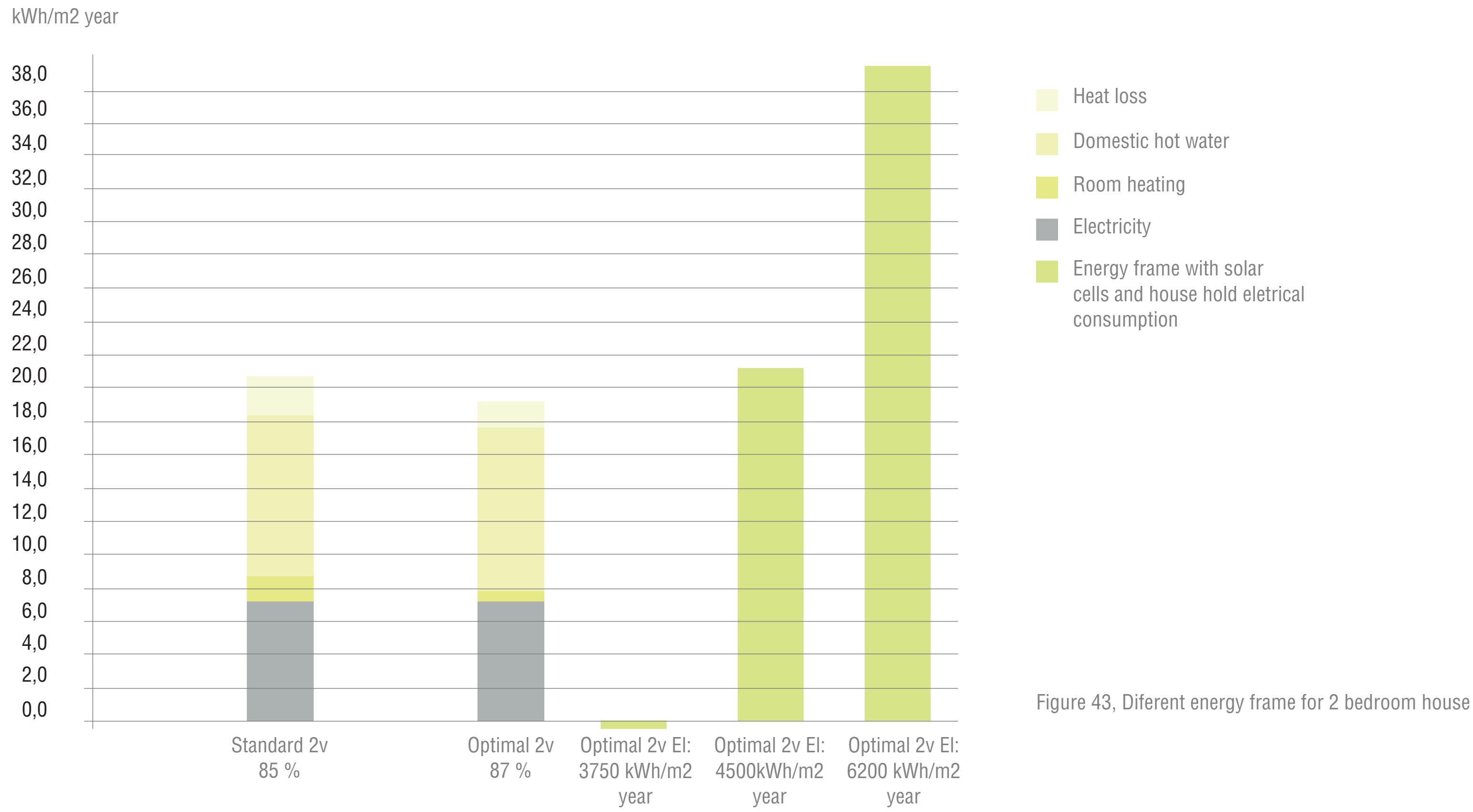


Figure 43, Diferent energy frame for 2 bedroom house

Energy frame

The primary goal has been fulfilled using passive strategies. The secondary goal is to achieve a self-sufficient house using renewable energy resources. The houses are equipped with solar cells that are integrated into the roof and the railing on the terraced house's second floor. The houses have been oriented with attention to the solar cells, facing the evening sun and the roof's shape has been designed with the functionality of the panels in mind.

In the effort to achieve a zero energy house, the future residents of the houses have a huge impact on whether or not the house will be within the designed consumption parameters. Old habits from former houses are often brought into the energy improved houses. These habits can increase the consumption of electricity and heating.

In the three-bedroom house, three different electricity consumption levels have been used: low, average and high. The values have been calculated using an Excel spreadsheet of Danish electricity consumption which describes the number of residents in the dwelling and the amount of electricity they consume.

The energy requirements are assessed according to the calculated energy consumption. The Be10 program uses different weightings according to which energy class is desired. For the 2020 building class, electricity consumption is multiplied by a factor of 1.8 and the heating by a factor of 0.6 [bygningsreglementet.dk, Generelt, 2016]. Electricity consumption is 'penalized' more than heating in the Be10 program by adding a greater loss of energy due to transportation in pipes from the manufacture to the consumer. Therefore, primary focus has been on implementing solar cells.

The optimal Be10 version of the three-bedroom house has an energy frame on 19.5 kWh/m2 per year. The table above shows how the different electricity consumption levels affect the energy frame. The house is equipped with solar cells on the roof and railing, and these panels produce a total of 26.5 kWh/m2 electricity per year.

According to the data from Be10 for the optimal model of the three-bedroom house, the energy consumption from the installations is 4.0 kWh/m2 per year. The figure 44 describes how the energy parameters vary due to different levels of energy consumption.

In the 'Home for Life' project, it was estimated that the family would consume 15 kWh/m2 per year of electricity. The low consumption level is therefore set to 15 kWh/m2 per year. If the family has a low energy consumption, then the house's electrical consumption can be covered by the solar cells. If consumption increases to a level above 22.7 kWh/m2 per year, the amount of solar cells will be insufficient.

The heating consumption in the houses is reduced by the use of a high efficiency heating recovery unit on 87%. To reach the zero energy class, the domestic heated water consumption must be covered using renewable energy resources. This could be in the form of an air-to-water heat pump that heats water for bathing, washing and under floor heating. The electrical consumption from the pumps can be covered by the solar cells if the family has a low consumption level.

The 'Home for Life' project, after the family had lived in the house for a year, concluded that they actually consumed twice as much electricity than what had been estimated. Therefore, in order to insure a total coverage of different electrical consumption levels, the solar cells should be increased by 30%, which entails the installation of approximately 45m2 of solar cells on the roof.

Project: The Green Village : 2v bedroom Terraced House Optimal values		
Main Data		
Energy frame BR2020		
Energy frame building 2020	19,0	kWh/m2 year
Heating	19,7	kWh/m2 year
El to the building operation	4,0	kWh/m2 year
Over heating in the house	0,0	kWh/m2 year
Output from specific source		
Heating pumps	0,0	kWh/m2 year
solar cells on roof	22,0	kWh/m2 year
solar cells on railing	3,9	kWh/m2 year
Acheiving Zero energy	Energy consump-tion	Energy frame with solar cells
Energy consumption		
El. consp. low	15	kWh/m2 year
El. consp. average	27	kWh/m2 year
El. consp. high	37	kWh/m2 year
Envelope		
Climate screen	129	m2
Share vindow area/gross floor area	26,4	%
Net area	111	m2
Gross area	129	m2
Transmission loss, climate screen	2,3	W/m2
Construction		
U-values		
Exterior walls	0,083	W/m2K
Roof	0,083	W/m2K
Foundation	0,095	W/m2K
Linie loss -values		
Foundation	0,020	W/mK
Assembly at doors and windows	0,000	W/mK
Windoes		
Frame type	wood/alu	
Glass	3 layer glas argon filling	
Uw-value for windows	0,67	W/m2K
Ug-value for windows	0,53	W/m2K
gg - value windows	51	%
LTg value	72	%
Window depth in wall	50	mm
Installations		
Compact aggregate	Yes	
Ventilation rate	0,5	1/h
Heat recovery units	87	%
Distribution water carried heat : underfloor heating in ground floor and bathrom room on 2nd. floor		

Figure 44, Main data from optimale Be10 model of 3 bedroo house

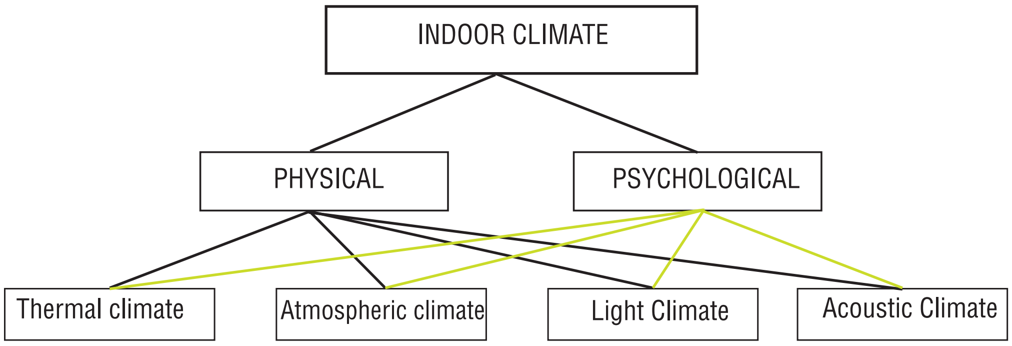


Figure 45, Indoor climate factors

Indoor climate introduction

The indoor climate consists of several parameters that can contribute to a pleasant or an unpleasant indoor climate. The indoor climate can be divided into physiological and psychological elements. The physiological elements cover the thermal and atmospheric climate, and the psychological the lighting and acoustic climate [Hyldegård, 2001].

The physical climate can be assessed differently according to the residents' psychological state and reverse. The indoor climate has a great effect on people's well-being. All these parameters have been considered and used to ensure a pleasant environment for the residents and enhance their quality of life. As shown in figure 45, the parameters of the indoor climate affect each other.

In the following text, the development of the houses' design will be discussed in terms of how the daylight, thermal and atmospheric parameters affect the indoor climate. The following design developments are shown in three different versions of the three-bedroom house. The versions will vary in amount of windows, shading settings and levels of natural ventilation.

All the versions have the same orientation, with living rooms facing south-west and most of the bedrooms facing north-east. The effects of daylight, thermal and atmospheric parameters on the indoor climate are tested in the following three versions of the three-bedroom terraced house:

Version 1:

Follows the minimum requirements for 2020 class, with a mini mum glass-to-floor area of 15%.

Version 2:

24.8 % glass-to-floor area

Version 3:

28% glass-to-floor area

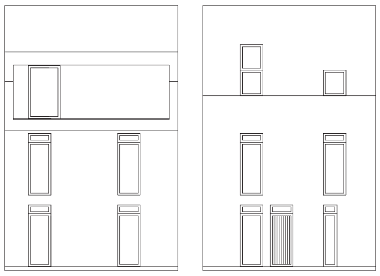


Figure 46, Elevation 1:200

Building information		
1 vers.		
Window percentage	15,0	%

Daylight factor, %

- 8,00
- 7,00
- 6,00
- 5,00
- 4,00
- 3,00
- 2,00
- 1,00

Building information		
2 vers.		
Window percentage	24,8	%

Daylight factor, %

- 8,00
- 7,00
- 6,00
- 5,00
- 4,00
- 3,00
- 2,00
- 1,00

Building information		
3 vers.		
Window percentage	28,0	%

Daylight factor, %

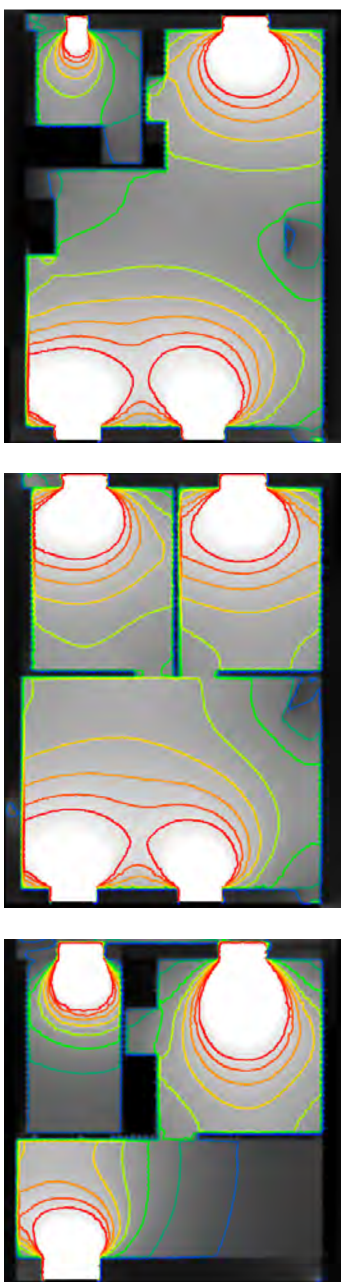


Figure 47, Version 1, daylight factor

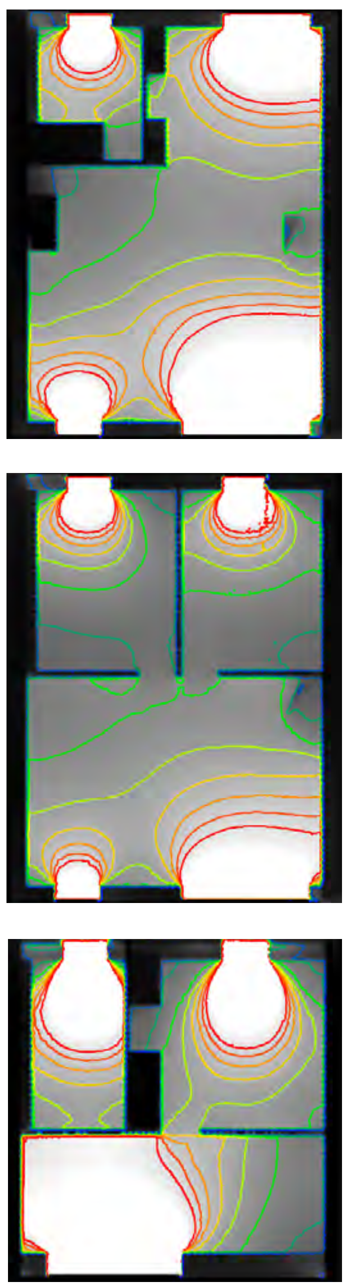


Figure 48, Version 2, daylight factor

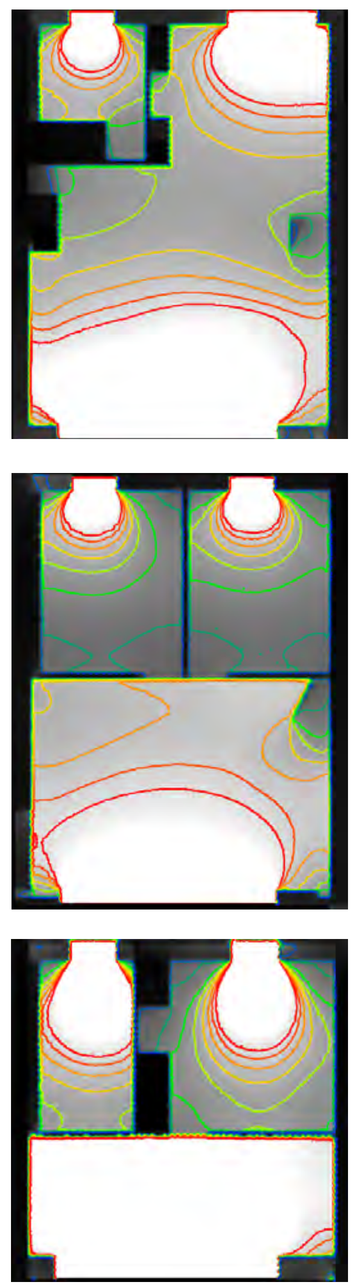


Figure 49, Version 3 daylight factor

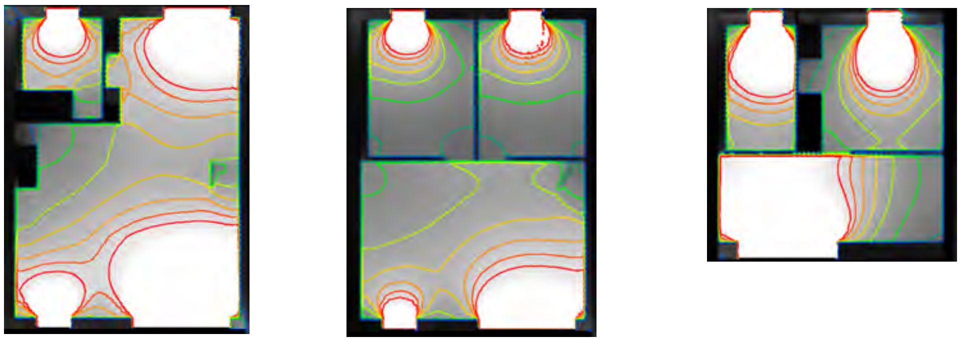


Figure 50, Version 2, white surfaces

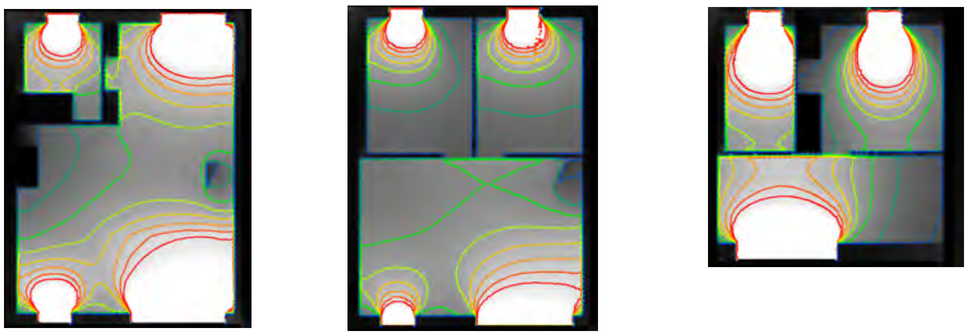


Figure 51, Version 2, Dark surfaces

Resultat oversigt, conclusion

In testing the lighting climate, the Velux Visualizer 2 program has been used. The Velux program has been used to test the daylight factor of the different versions in all the rooms on all floors. The architectural expression of the facade with changing windows is illustrated in each version. The objective was to insure a daylight factor (DF) of at least 3%. The daylight factor is used to determine the minimal daylight conditions which occur on an overcast day. The outdoor lighting strength is set to 10,000 lux. The daylight factor is per definition independent of the windows' orientations [Johnson & Christifferson 2008].The choice of high windows has been made in order to increase the exposure and ensure a deeper penetration of light into the rooms and to provide a view to the surroundings from all the rooms. The three versions are evaluated on the daylight factor, view to surroundings and architectural expression.

1 version, 15 % windows, see figure 47

- Minimally fulfills the requirements for daylight in 2020.
- Sufficient daylight in all bedrooms, with DF over 3%.
- Insufficient daylight in living rooms and bathrooms.
- The facade appears closed off and provides no proper view of the surrounding environment.

2 version, 24,8 % windows, see figure 48

- The bathrooms windows are increased to achieve a higher DF and improve the rhythm of the façade.
- The north-east facade is architecturally coherent, provides proper lighting and insures views and privacy.
- The amount of windows on the south-west facade has been enlarged so as to increase the amount of light and provide residents with a larger connection and view to the surrounding context without being overexposed.
- The houses are displaced by two metres, as shown in the urban presentation. The displacement insures both family privacy and shading. The increased amount of window area will provide adequate illumination in the whole house.

3 version, 28 % windows, see figure 49

- South-west facade consists almost completely of windows.
- The overexposure between the indoor and outdoor environment is increased to a point where the residents can feel overexposed to the surroundings.
- Can cause excessive overheating during the summer.
- This can cause the family to use solar shading during the winter, thereby decreasing the passive heating and sunlight exposure. The solar shading can therefore result in increased use of heat and electrical lighting.

The materials on the surfaces inside a house have a great effect on the distribution of the light from the windows. The second version of the house has been tested in three different scenarios: one with all surfaces white (figure 50), one with all surfaces coloured dark (figure 51) and a third scenario with a combination of light, dark and warm wood colours on the surfaces (figure 47-49).

The scenario with only white surfaces is overexposed with light, the illumination is too efficient and can cause glare. The dark surfaces absorb all light, which penetrates the windows and does not insure an efficient illumination. The combination of dark floors on the ground floor with white walls and a wooden element provides an illuminated room with no glare. The upper floors have light wood flooring and white walls, which ensures a proper illumination and a warm atmosphere.

Figure 52, Elevation 1:200

24H	Units
With overhang	1/h
Daily average temp.	celsius degree
Temp. variation	celsius degree
Maximal temp.	celsius degree

Changing average change					
0,5	1,0	1,5	2,0	2,5	3,0
32,5	25,9	23,1	21,5	20,5	19,8
2,3	2,6	2,9	3,2	3,5	3,7
33,7	27,2	24,5	23,1	22,2	21,2

Figure 53, Version 1, 24H

Changing average change					
0,5	1,0	1,5	2,0	2,5	3,0
39,3	30,6	26,6	24,4	22,9	21,8
3,6	3,9	4,1	4,3	4,6	4,8
41,1	32,6	28,7	26,5	25,2	24,2

Figure 54, Version 2, 24H

Changing average change					
0,5	1,0	1,5	2,0	2,5	3,0
41,1	32,0	27,8	25,3	23,6	22,5
4,1	4,3	4,5	4,8	5,0	5,2
43,2	34,2	30,0	27,7	26,1	25,1

Figure 55, Version 3, 24H

- Without overhang:
  U-value : 0,67 kWh/m2
  g-value : 0,51
- With overhang:
  U-value : 0,67 kWh/m2
  g-value : 0,51
- With overhang + shading:
  U-value : 0,67 kWh/m2
  g-value : 0,51
- Without shading:
  U-value : 0,81 kWh/m2
  g-value: 0,51
- Without shading:
  U-value : 0,67 kWh/m2
  g-value : 0,55
- Without shading:
  U-value : 0,67 kWh/m2
  g-value : 0,60

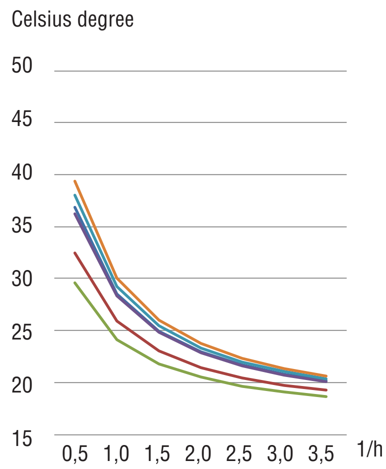


Figure 56, Version 1, 24H

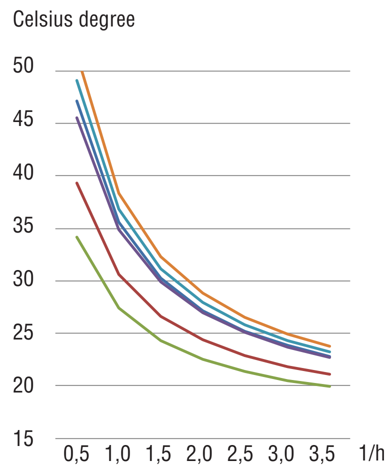


Figure 57, Version 2, 24H

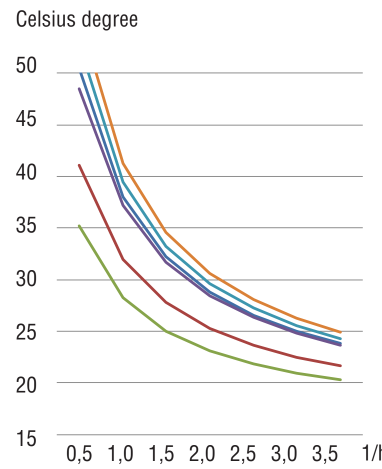


Figure 58, Version 3, 24H

Monthly data	Units
With shading	1/h
Total energy consp.	kWh/m2 year
Energy consp. cooling	kWh/m2 year
Energy consp. heat	kWh/m2 year

Changing average change					
0,5	1,0	1,5	2,0	2,5	3,0
23,5	19,2	19,8	21,7	24,3	25,5
4,8	0,3	0,3	0,3	2,1	3,8
18,7	18,9	19,5	21,4	22,2	21,7

Figure 59, Version 1, Monthly

Changing average change					
0,5	1,0	1,5	2,0	2,5	3,0
33,2	26,6	25,6	26,7	28,7	31,1
9,3	1,9	1,1	1,1	1,1	6,3
23,9	25,6	24,5	25,6	27,6	33,7

Figure 60, Version 2, Monthly

Changing average change					
0,5	1,0	1,5	2,0	2,5	3,0
35,9	28,3	26,5	27,4	29,0	31,4
11,9	3,5	2,0	2,0	2,0	2,0
23,9	24,8	24,5	25,4	27,1	29,4

Figure 61, Version 3, Monthly

- Without shadow
- With overhang
- Without shading:
  U-value : 0,81 kWh/m2
  g-value : 0,55
- Without shading:
  U-value : 0,67 kWh/m2
  g-value : 0,55
- Without shading:
  U-value : 0,67 kWh/m2
  g-value : 0,60

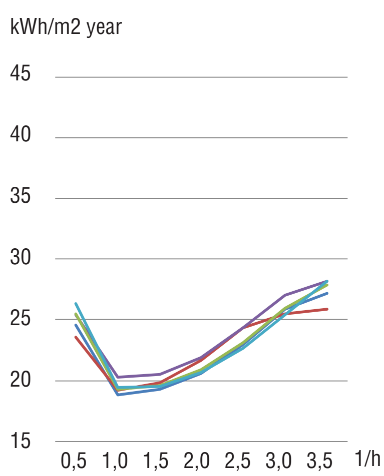


Figure 62, Version 1, Monthly

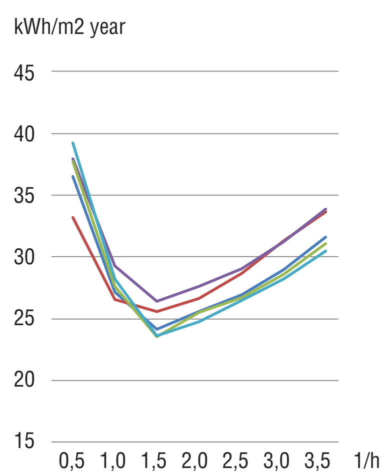


Figure 63, Version 2, Monthly

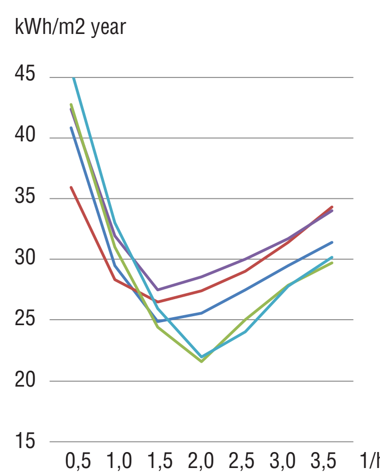


Figure 64, Version 3, Monthly

Main Data			
Energy frame BR2020	Category A	Category B	Category C
Dissatisfied	6 %	10%	15 %
Winter temperature (degrees)	21-23	20-24	19-25
Summer temperature (degrees)	23,5-25,5	23-26	22-27
Air quality, dissatisfied	15 %	20 %	30 %
Air quality (ppm)	460	660	1190

Figure 65, DS 1752 categories

Thermal indoor climate

The thermal indoor climate is affected by the construction of the building and the people occupying the rooms. The construction is related to the U-value of the walls, roof and foundation and to the thermal bridges around the windows and joints in the construction. The lower the U-value, the lower the transmission loss through the construction.

The windows can contribute positively to a pleasant thermal climate during the winter with passive heating but during the summer they may be the cause of excessive heating. The people occupying the rooms can contribute to the temperature in a room with different activity levels and clothing. The goal is to find a balance between activity, clothing and comfort level of temperature in a house. The Danish DS 1752 specification contains different categories for indoor climate requirements due to function and desired amount of satisfied people occupying the room. In figure 65, the three different categories are described with amount of dissatisfied people, temperature level summer/winter and the air quality.

Category B is often used in residential buildings, with a medium expectation. The maximum allowed carbon dioxide (CO_2) concentration level in the table is without the exterior air's CO_2 concentration, which is typically 350 ppm. The maximum allowed concentration level in a room totals 660 ppm + 350 ppm = 1010 ppm. [DS 1752, 2001]

The three different versions of the terraced house have been tested in 24-hour daily averages and in a monthly Excel spreadsheet. The spreadsheets can provide an estimate of the thermal climate and energy consumption of the building regarding heating and cooling. The 24-hour daily average spread is a simplified way to estimates in a design process how the different design features, such as the amount of windows, shading, ventilation, people and equipment load can affect the indoor climate. Instead of calculating all the rooms in the house, I have used a specific room that is highly likely to overheat. That room is the living room on the ground floor, which is connected to the first floor living room by a large opening in the floor structure and has large windows to the south-west. The dwellings are designed with bedrooms to the north-east, which makes it unlikely that these rooms will overheat during the summer due to reduced sun exposure.

Each version of the house is tested with following parameters:

- No shading
- Shading
- Different amount of natural ventilation
- Windows' U-value and g-value.

The differences between the three versions are in terms of the amount of windows. Hence, the greater amount of window area facing south-west, the greater the overheating during the summer. The category B for thermal indoor climate is achieved in the first version with a natural ventilation of 1.5 1/h, the second of 2.5 1/h and the third of 3.0 1/h with the only shading being the overhang.

The windows' U-value and g-value have a great effect on how the indoor climate and energy frame can be improved. This is illustrated in figures 53-64. The U-value is the weighted U-value of the glass and frame, and measures how well the window is insulated. The g-value describes how much of the sun's heat is allowed to transfer through the glass. A g-value of 0.51 allows 51% of the heat to be transmitted into the indoor climate.

The higher the g-value, the greater the passive heating during the winter and worse the overheating during the summer. The difference between a window with a U-value on 0.81 kWh/m2 per year and g-value of 0.51 versus a window with U-value of 0.67 kWh/m2 per year but with the same g-value has a very little effect on the indoor climate during the summer. The difference is greater between the two windows during the winter. A higher U-value allows a higher transmission loss through the window, which increases the heat consumption. See figures 59-64xx

In comparing the three different versions of the house according to the two indoor climate criteria, daylight and thermal, my assessment shows that the second version of the terrace house has the optimal balance between amount of windows according to proper daylight, comfortable thermal indoor climate and energy frame. The windows have a U-value of 0.67 kWh/m2 per year and a g-value of 0.51, which reduces overheating during the summer and provides sufficient passive heating during the winter, with minimal transmission loss through the windows.

The solar shading strategy plays a great part in achieving a holistic design, incorporates the aesthetics, functionality and the environment in a house. Figures 53-58 shows the effect of different shading strategies on the indoor climate. The dwellings are designed with three shadow strategies. The first has an overhang that provides shade for the high summer but allows the low winter sun to enter. The second shadow strategy integrates external solar shading curtains on the facade which are more effective than those indoors. This is because the external curtains can more effectively stop the heat from the sun from entering during the summer. The internal curtains reduces solar glare. The third strategy uses vegetation as shade during the summer, in the form of deciduous trees and ivy that can grow on wire and walls.

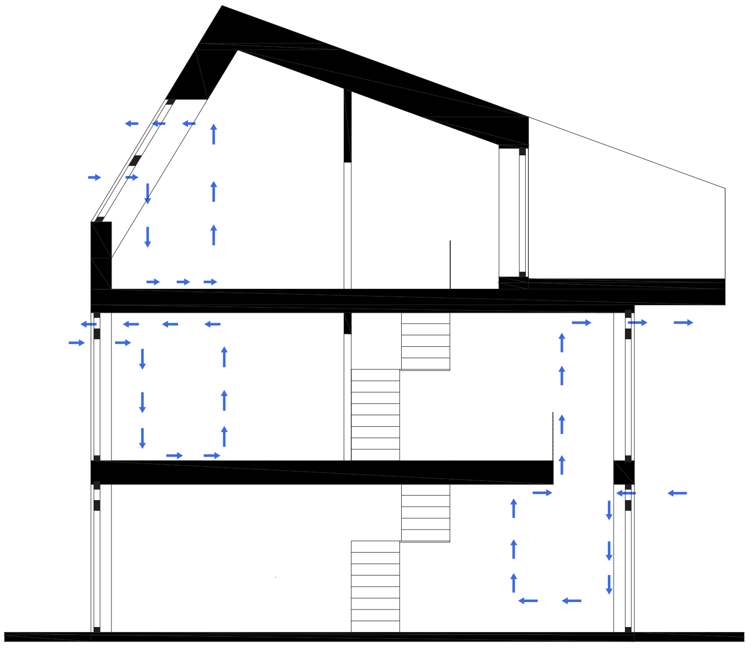


Figure 66, Single sided ventilation

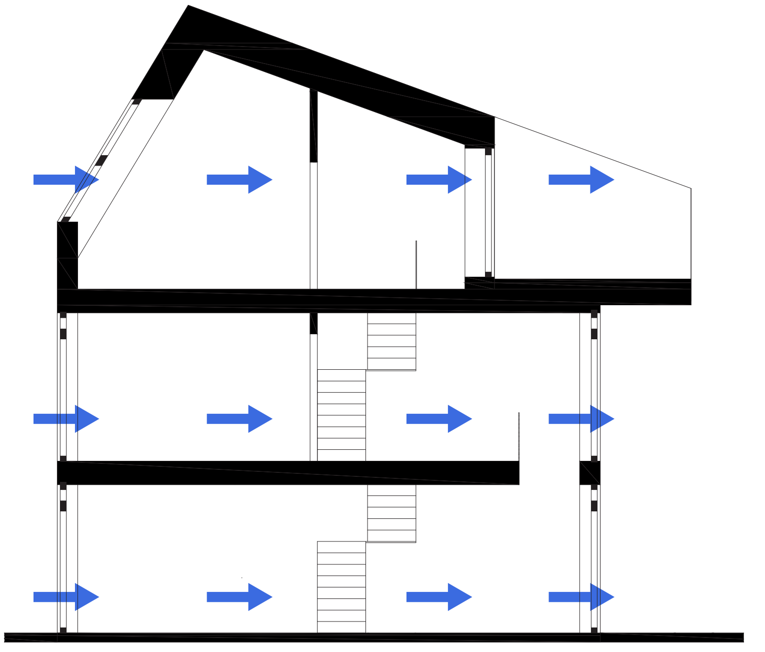


Figure 67, Cross ventilation

Ventilations strategies, natural

The ventilation strategies in the houses are divided into natural and mechanical ventilation strategies. Both strategies have been implemented in the design of the dwellings from the sketching phase to insure a holistic coherent design.

The natural ventilation strategies are thoroughly described in the analysis on page 91. The strategies applied to the houses are inspired by Per Heiselberg's book, 'Design of Natural and Hybrid Ventilation' and from reading about the residents' experiences in the Comfort House project.

Per Heiselberg developed a method to approximate the depth of a room to achieve efficient natural ventilation. The parameter for cross ventilation is that the depth of the room must not exceed 5xH<W, i.e., the room cannot be deeper than 5 times the height of the room. The first two floors in the terraced house has a height of 2,35 metres, which allows for a total depth of 11.75 metres according to the cross-ventilation parameter. The terraced houses are 9 metres long [Heiselberg, 2006].

All the bedrooms and bathrooms have been dimensioned according to a single-sided ventilation parameter by which the room cannot be deeper than 2.5xH<W. The rooms can be no more than 5.8 metres deep, and they are 4.16 metres deep. These are but estimated values, but they give an idea of how to create a room with good proportions suited to ventilation. The different natural ventilation strategies are shown in a section of the house in figures 66-67.

The passive design houses in the Comfort project were not designed to exploit natural ventilation, and residents felt restricted by not being able to leave the windows open while they were sleeping or away from the house. This problem has led to a more intuitive design of these houses.

The windows in the houses on the two lower floors consist of two parts: a tall slender window, and above it a small window in same width placed on top as shown in the section of the house. The small windows used to ventilate during the night and while the family are away during the warm period of the year.

The parents can safely have a window open in the children's bedrooms without concern for their safety during the night. It is recommended that all the windows should be able to be controlled by a mechanical system so as to insure proper ventilation which the family can overrule when needed.

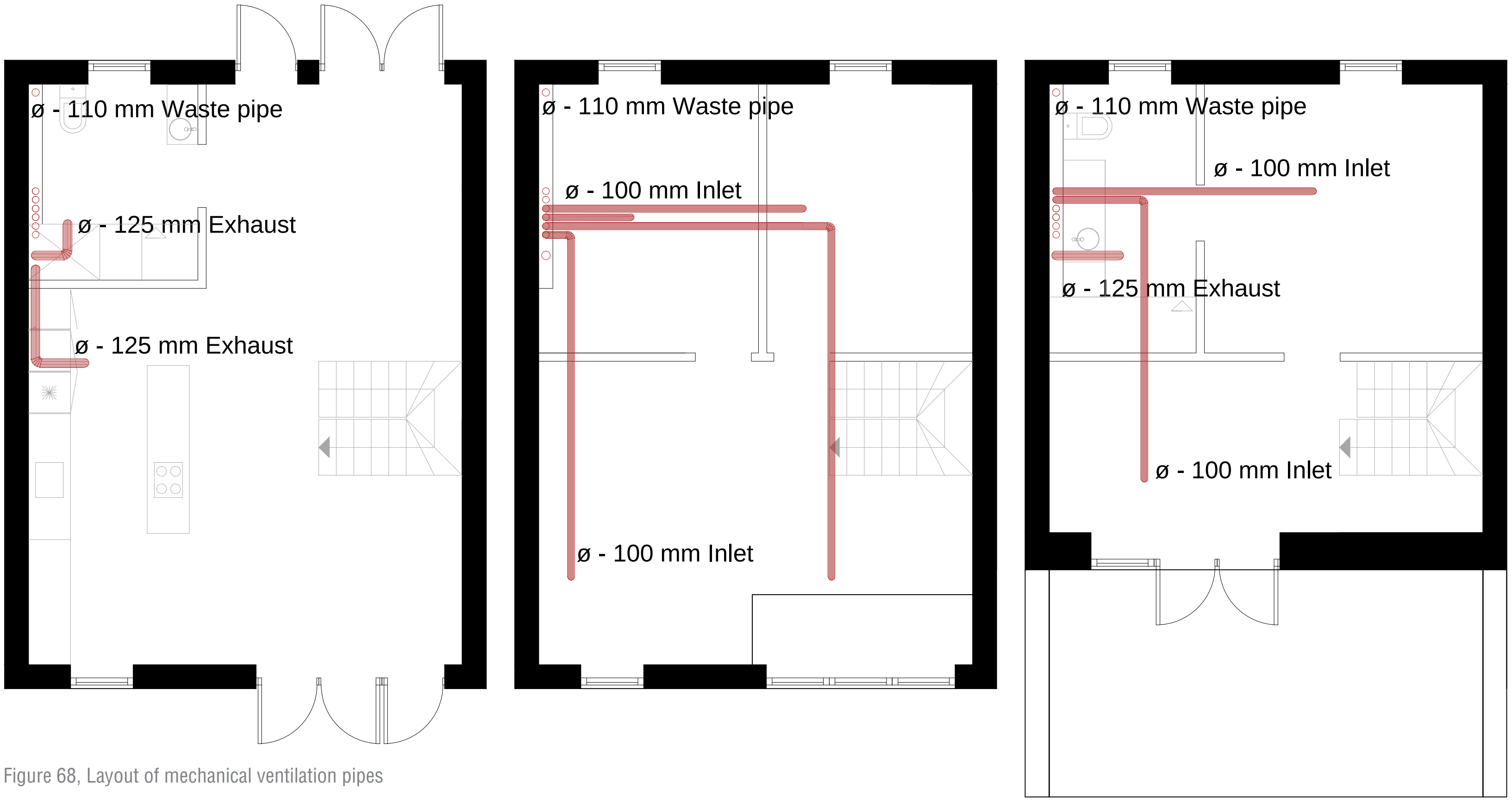


Figure 68, Layout of mechanical ventilation pipes

Ventilations strategies, mechanical

The mechanical ventilation strategy is implemented in the house layout. The compact ventilation unit is placed in the ground floor bathroom, in a closet with all the technical installations. Figure 68 shows how the pipes from the ventilation unit are hidden in an extra wall which goes through all the floors. The fresh air can reach all the rooms in the house by placing the pipes in the floor structure in a suspended ceiling.

The pipes are dimensioned to fulfil category B of the Danish DS 1752 specifications. The Danish building regulation demands that a home ventilation system be designed to exhaust with a volume flow on 20 l/s from the kitchen, 15 l/s from bathrooms and 10 l/s from the laundry and basement room. Exhaust pipes have been installed running from the kitchen and bathroom. [bygningsreglementet.dk, beboelsesbygninger, 2016]

The velocity of the pipes is set to 4 m/s which is a standard velocity in domestic buildings. If the velocity is increased to 8 m/s, the pipes have to be given additional sound insulation to muffle the noise from the pipes [Hvenegaard, 2007].

There are various geometric shapes for pipes: they can be produced as rectangular or cylindrical (round). The cylindrical pipes are more frequently used in building projects because they are cheaper, easier to install, denser and easier to insulate than rectangular pipes. The cylindrical pipes have been applied in this project to minimised cost and ease the technical installation process [Stampe, 2000].

(1) **Roof structure**

Zinc plates

20 mm roof plywood

570 mm insulation, lamdba 37

21x95 mm split wood slates

13 mm plasterboard

(2) **Wall structure**

30 mm high reinforced concrete plates

280 mm rigid insulation PUR lamdba 22

30 mm high reinforced concrete plates

(3) **Floor structure**

22 mm oak floor board

220 mm concrete deck, impost 100 mm

137 mm rigid insulation PUR lamdba 22

13 mm plaster board

(4) **Floor foundation**

22 mm tiles

130 mm concrete with underfloor heating pipes

20 mm edgerigid insulation PUR lamdba 22

440 mm Polystyrene

Sand fill

Concrete base

(5) **Wall foundation**

150 mm light weight block

180 mm Polystyrene

30 mm high reinforced concrete plates

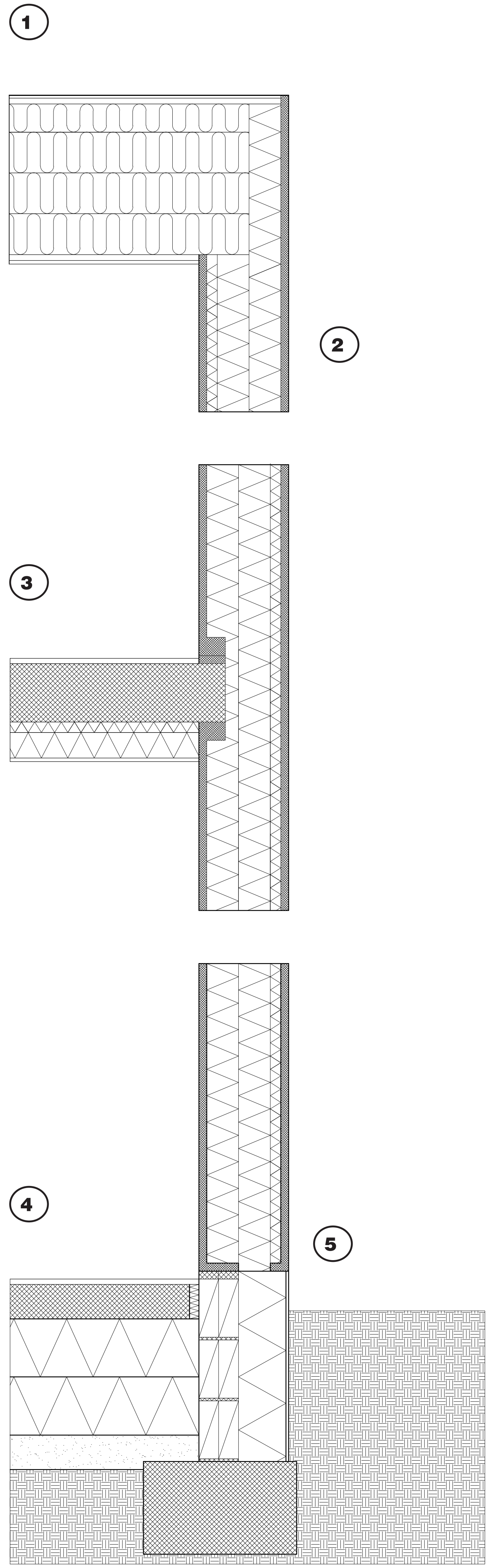
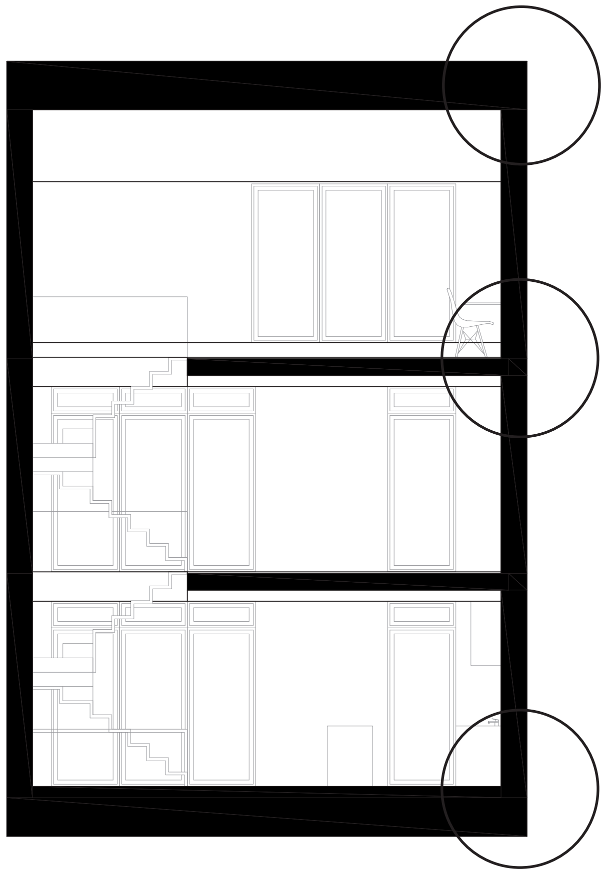


Figure 69, Constructional details 1:20



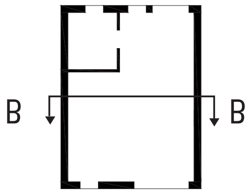


Figure 70, Section B-B 1:100, shows where the construction details in figure 69 are placed in the house

Construction

One of the objectives of this project was to use a simplified construction principle so as to reduce construction time. The two types of terraced houses are thus designed using the same construction principle. The houses have the same depth, floor height and vary only in how their width and in the amount of windows in the facades. The functional layout and placement of rooms are similar.

The construction principle in the houses consists of two main elements: load bearing walls and soundproof concrete plates used as floor structure. All the interior walls are non-load- bearing in order to enable the houses to accommodate the needs of different families inhabiting the houses over time. The technical details of the construction are shown in figure 69.

The walls shared between the terraced houses are the load-bearing walls, on which the concrete slab rests. The roof's load-bearing beams rest on the shared walls between the houses, the principle is illustrated in figure 68. The floor structure is based on the single tensioned strategy, with only two load-bearing places.

In accommodating the desire of slender construction, a newly developed wall sandwich element is used in this project. The element has been developed by the firm Connovate, which is a co-operative venture between the three Danish companies Ambercon, Arkitema and Confec sponsored by Realdania. Realdania is a Danish association supporting Danish building initiatives to improve the environment. The sandwich element consists of a front and rear compact reinforced composite (CRC) concrete plate of only 30 mm. Between the plates a rigid PUR insulation material is used.

The company supplies the sandwich element in four different thicknesses to accommodate different requirements for the U-value. In this project, a 340 mm wall is used with a U-value of 0.083 W/m2K, which can meet the requirements of the 2020 building regulations [Connovate, u-værdi 2016]. The use of CRC concrete and PUR insulation allows for a slender wall construction with the same low u-value as a present traditional concrete sandwich element. [see page 94-95 for more information]

The sound proof concrete structural floor is a prestressed concrete slab. The element is produced as light weight CRC concrete with a characteristics compressive strength on 55 MPa. The element can be delivered in different length up to 7200 mm and with a default width on 600 or 1200 mm [Expan ,Lyddæk, 2016].

The structural floor dimensions and required strength have been found with using the defined payload for load categories from A to H in a Danish technical encyclopaedia. The category A1 Residence construction requires the structure to carry a payload of 1.5 kN/m2. The payload includes people, furniture and fixture on each floor structure in residential buildings [Mohr, 2011]. To fulfill the requirements, the deck has to be 220 mm thick, with wire reinforcement code 33 [Expan, Lydæk, 2016]. The load capacity deck table is placed in Appendix A on page 112-113.

To fulfill the Danish building regulations for fire protection, the sandwich elements have been designed and tested to meet the Danish fire safety standards for BS-Building component. According to the Danish building regulations, the exterior construction in a single-family house which adjoins or lies within five metres of the next building must meet the BS-building component 60 standard.

The fire class BS-Building component 60 is one of two sets of fire protection standards. The constructions which fulfill these standards have to be constructively sound and fire resistant for at least 60 minutes and not contribute to the spread fire or smoke [bygningsreglementet.dk, Brandforhold 2016].


Figure 71, Court yard in the Green Village

Conclusion

This main focus of this thesis was on how to create sustainable dwellings. Two main themes were discussed:

- How to create sustainable low-consumption dwellings which could be a new interpretation of the single-family houses in a more sustainable and dense frame.
- How to create a dwelling with a pleasant indoor climate using both traditional and innovative climatic design methods which would be intuitive for the families and reduce energy and heat consumption.

These questions were addressed by using the integrated design process method to ensure well-documented, holistically designed dwellings.

The analysis phase was used to gather extensive information to address these two themes. In a comparative study of two types of house, the single-family house and the terraced house, it was concluded that the terraced house is an optimal type for creating a new sustainable dwellings in a dense city landscape. It is a new interpretation of the suburban house. The terraced house can be placed in a dense urban landscape and still be able to provide each family with a sense of private space and green areas.

To narrow the field of low-energy house concepts, the two concepts of 'passive' and 'active house' were researched and documented. The goal of designing sustainable dwelling with a satisfying indoor climate was achieved by using the active house concept. The concept takes a holistic approach by considering the effect of each design and building phase on three spheres: the environment, energy and indoor climate. The passive house construction focuses mainly on reducing heat consumption; however, this often results in unpleasant overheating during the summer.

The three spheres have been used to create a more intuitive sustainable dwelling with close connection to the surrounding landscape. The environmental sphere focuses on the positive interaction with the local environment, using natural resources and minimal CO2 impact. The single-family and terraced house have been merged together to create a denser dwelling able to attract people who prefer single-family house. To accommodate a larger diversity of family compositions, two types of terraced house have been designed: a 165m2 three-bedroom house, and 129m2 two-bedroom. The urban landscape has been created by displacing the terraced houses so as to create positive spaces that can create life between the buildings. The urban landscape becomes an extra quality and provides the residents with high quality of life.

The residents' cars have been moved underground to create spaces between the buildings and making them safer for the children to play. The courtyards become places where the residents can relax and have social activities, and walking and use of bicycles is promoted. By breaking the strict rigid functionalistic urban planning, the green areas among the building become alive. Not only are there created life between the buildings, but the site is designed to become a positive contribution to the area by having a play area for the children, rainwater collection, social gathering places for people to meet and a great amount of vegetation in the form of trees, bushes and wild green areas.

The second sphere is the indoor climate, which has been improved by implementing climatic design strategies, also called 'passive strategies', that can ensure that all the houses have access to daylight and natural ventilation. All the houses on the site have been placed to face south-west to ensure plentiful exposure to daylight in the hours the families are at home over the whole year.

The goal was to reach the Danish energy class 2020 by applying only the passive design strategies. This has been achieved by using the integrated design process. The three-bedroom house type has an energy frame of 19.5 kWh/m2 per year, and the two-bedroom an energy frame of 19.0 kWh/m2 per year.

The envelope has been developed to have a minimal climate screen, thermal loss and a balanced amount of windows. The floor plan layout has been designed following the passive house concept with placing almost all the bedrooms face the north-east and the common rooms to the south-west. The bedrooms are sheltered from overheating during the summer, while the common rooms can be passive heated by the sun during the winter.

A pleasant indoor climate has been achieved by testing three versions of the three-bedroom house type with different amount of windows, U-value and natural ventilation rate. By integrating external solar shading in the envelope, the overheating during the summer is reduced. The windows are designed to supply the house with natural ventilation when required. All the materials for the project have been chosen with consideration for the production, transportation and construction on site, thus minimizing carbon dioxide emissions. Almost all the materials can be recycled or re-used when the houses are demolished.

The third sphere is energy, which is about integrating renewable resources in the envelope. The roof on the terraced houses has been shaped in order to more effectively integrate the solar cells. To reach zero energy, it is recommended that air-to-water heat pumps be installed for producing heated water. The high efficiency heat recovery unit in the ventilation system and the underfloor heating can provide the house with renewable heating resources.

Family lifestyle in a low energy house has a great effect on how well the house will actually perform as an active house. This has been tested using three different electrical consumption levels. If the family has a very low electrical consumption of 15 kWh/m2 per year, the solar cells on the roof can cover all their electrical consumption in the houses, including the pump in the heat pump system. If the family consumes more than 22.7 kWh/m2 per year of electricity, then the solar cells can presently not produce enough energy.

A sustainable dwelling becomes more of a living organism which the family has to understand and learn how to live with. However, the benefits of these dwellings are great: they provide fresh air, less polluting materials, a large amount of daylight and integrated renewable energy resources.

During the analysis and sketching, I found a new sustainable aspect that could be integrated in the houses. It is a constructive simple system that allows the families to change the interior walls according to their changing needs and desires. This ensures that the houses will remain adaptable to the families' changing needs and different ideas of living in open or closed spaces or a combination.


Figure 72, The breathable house

Discussion:

Interaction between nature and humans by creating dwellings that live

In 1923, the famous French architect Le Corbusier declared that 'a house is a machine for living'. During my studies at Aalborg University, I was introduced to the Integrated design Process method (IDP) developed by Mary-Ann Knudstrup. The goal of the IDP method is to create sustainable holistic architecture where the technical and architectural elements are integrated in order to achieve a technically effective, aesthetic building with low energy consumption.

During my analysis phase, inspired by Brunsgaard's study of 'Comfort House' passive housing construction project, I learned about the how residents' behaviour can affect the house's energy and heat consumption. See figure 72. Some of the dwellings in the Comfort House project were not designed for people but designed more to fulfill building regulations. Residents could not open the windows, and the large windows facing south created extreme overheating during the summer.

The human relations and interactions with houses can easily be overlooked if there is too much focus on the technical installations and low energy consumption standards.

If the goal for Denmark is to become more sustainable, houses should be designed so that they are easier for residents to interact and more intuitive to understand. Climatic design can be used to allow the house go from being a 'machine' to live in to a house which 'lives'. The house can live with allowing the windows to become the sources of fresh air, passive heating and daylight. The gutters and garden collect rainwater for use in the house, the roof becomes alive by giving electricity and the exterior walls can breathe.

While conducting research for this thesis, I discovered a new Danish project called the 'The Breathable House'. The project seeks to design a new low-energy house type that can eliminate the use of mechanical ventilation by using materials that can breathe. Focus is also on eliminating toxic degasification from the building by using organic materials.

The organic materials can transport moisture through the construction without harming the walls or losing heat. The house is built from wooden boards, insulated with paper wool, and the roof is coated with straw. The breathable house was erected in September 2015 and is now undergoing a thorough assessment. The Breathable House project has been developed through a teamwork between Egen Vinding & Daughter, HOUSE architects, Stråtagets kontor, Technological institute and Denmark's Technical University [Kaarup, 2015]

I believe the IDP method is a viable strategy for creating better buildings, enabling architects and engineers to consider, from the very first sketching phase, the integration of the technical, architectural and human aspects in the house. The residents have to be able to relate to their house and understand it without a complicated help manual or technical support line.

The connections between the surrounding environment, the dwelling and human behaviour must be increased so as to insure that the low consumption sustainable way of living will become a great and lasting success in the modern world. It has to be easy and intuitive to be sustainable in order to meet the needs of all the different families and attitudes in Denmark. This project is a proposal for creating alternative sustainable dwellings that can promote living in dense cities but with a sense of life quality from the suburbs single family houses.

Analysis

Introduction to the analysis

For centuries, the human race has been on a constant search for new ways to improve everyday life. However, continuing technological advances have also resulted in a every greater consumption of non-renewable energy sources.

In 1987, the UN decided to form the Brundtland Commission, whose report, entitled 'Our Common Future', was intended to raise worldwide awareness about the catastrophic consequence of technological development on the environment. The report called for a 'sustainable development ' that could meet the needs and aspirations of the present without compromising the ability to meet those of the future' [WCED 1987, page 34].

According the report, the production, development and consumption sectors would need to create sustainable alternatives to energy production and consumption of materials. Since the report was written in 1987, various sustainable solutions have been developed, such as production of renewable energy sources e.g. solar cells, recycling and reuse of materials and designing products that are more energy efficient.

Residential buildings are one of the largest energy consuming products in the world; they are responsible for 30% of worldwide energy consumption both worldwide and in Denmark. Efforts to reduce consumption have led to the development of a new residential building, the low energy house [Larsen 2011].

In Denmark, the development of low energy housing has resulted in the emergence of the Danish Building Regulation energy classification system. The classifications are intended to ensure that a set of requirements and regulations are fulfilled in order to achieve more energy-efficient residential buildings [Energiberegning af nye huse 2014].

The international construction sector has created different approaches to producing energy efficient housing facilities. Architects and scientists in Germany have developed a standard for a 'passive house' designed to efficiently exploit passive heating from the sun, electronic devices in the home and from residents so as to reduce the additional heating requirements [Passive homes 2014]. In Denmark, the research in creating an optimal low-energy building has resulted in the 'active house' concept, which is focused on reducing consumption and become self-sufficient with implementing e.g. solar cells.

The constant effort to reduce energy consumption in dwellings has also resulted in some negative consequences. The houses may become uncomfortable because of the overheating during the summer and because of strict ventilation rules that consist mainly of mechanical ventilation. The aim of this project is to develop low energy consuming dwellings with a focus on the human behaviour, climatic design and use of healthy materials in order to create better and healthier homes for the Danish families all year around.

In Denmark, there have been two major residential building projects that have focused on researching and developing new alternative dwellings: the passive house project called 'the Comfort House' and the active house project known as the 'Home for Life'. Both projects are examined in the following chapter 1 to highlight successful and unsuccessful solutions. The opinions of the test families are included in order to create a better understanding of human behaviour in a low energy house.

This analysis is divided into five chapters.

CH. 1.

Low energy houses, energy frames

Energy class	Energy frame
2010, standard	52,5 kWh/m2 per year (x) + (1650 kWh pr year/heated floor area) = kwh/m2 per year (x) is max. allowed consumption of energy for heat, ventilation, cool and domestic hot water per m2
2015, Low energy	30 kWh/m2 per year+ (1000 kWh pr year/ heated floor area) = kwh/m2 per year
2020, Low energy	20 kWh/m2 per year
Zero energy	0 kWh/m2 per year The zero energy class can be fulfilled when the erected building can produce the amount of energy and heat it is consuming with active solutions
Plus energy	+ 0 kwh/m2 per year Plus energy house can produce more energy and heat than it consume annually with active solutions.

Figure 73, Energy frame

Energy classifications

The low energy house is the dwelling that has been promoted as most promising for the present and future population of the world. This chapter describes the different low energy classes, energy concepts and compares key features of the passive and active house. The comparative study of the two types of house will be used to evaluate the qualities and drawbacks in the recently developed Danish projects: the passive 'Comfort House' project and the active house 'Home for Life' .

According to a study performed by Henning Larsen architects, the design of a building's envelope is responsible for up to 40% of the building's future energy consumption [Kongebro 2012]. Therefore, future buildings should be developed so that they can integrate the technical and architectural solutions from the very first phase of a building project. In this light, I will evaluate the technical-architectural solution in the both the passive and active house projects.

In 2006, the Danish building regulation agency issued a new set of stricter building regulations for energy and heat consumption. The regulations made it mandatory to perform energy calculations on all newly constructed buildings in Denmark. The calculations were intended to ensure that the energy frame of new buildings does not exceed the permitted consumption threshold.

All the energy classes developed on the basis of this regulation take their point of departure in how much a traditional Danish house is allowed to use, with each class defined as a given percentage of reduced consumption of the traditional house.

The energy classifications are divided into two classes; low energy class 2015 and building class 2020. The 2015 regulations become mandatory for all newly constructed buildings in Denmark constructed after 2015, while the 2020 regulations take effect in the year 2020. In April 2009, the EU made a revision of EU building regulations stipulating that all new buildings constructed after 2018 should be built as zero energy houses. Figure 73 describes the energy classes [Dansk byggeri, Energiklasser 2016].

Figure 74, Stenagervænget 43

Figure 75, Stenagervænget 41

Figure 76, Stenagervænget 45

Figure 77, Home for life exterior

Figure 78, Home for life, living room

Figure 79, Home for life, night

Low energy building projects in DK

The development of low energy houses in Denmark has accelerated, and new theoretical and practical solutions are being continually developed. To obtain a greater knowledge about constructing low-energy houses, several Danish construction and architectural firms have participated in pilot projects that tested the theoretical solutions to actual construction projects.

In 2008, the Danish company Saint-Gobain initiated a collective project of constructing 10 single-family homes based on the German passive standard, adjusted to the Danish building techniques and architectural expression. The comfort house was a pioneer project in Denmark as regards the development of passive houses. The pioneer project was developed in order to gather greater knowledge about how to coherently combine the technical and architectural aspects of passive house design. See figure 74-76

The project aimed to create a more comfortable indoor environment and attractive new dwellings for the families in Denmark. Alongside the project, a doctoral student from Aalborg University, Camilla Brunsgaard, collected data from three test families in order to obtain a more detailed understanding of human behaviour in a passive house. The houses' indoor climate conditions were evaluated using simulation, objective calculations and from the test families' subjective perspective of living in the houses. The findings from Camilla Brunsgaard's research has been used in this project to obtain a more thorough understanding of how to improve technical and architectural solutions with relation to the human behaviour [Brunsgaard 2009].

In 2008, VKR Holding developed the concept of an active house in collaboration with a consortium of Danish building companies and architectural firms. To obtain a greater knowledge and skills in developing active houses in Denmark, they designed and built a prototype called 'Home for Life', a single-family house placed in Lystrup, on the outskirts of Aarhus municipality. See figures 77-79

The house was completed in 2009, and a test family was selected to move in. The test family wrote a diary about their experience of living in the test house, with both negative and positive responses, in order to provide a better understanding how to build an active house for ordinary families. During the test period, the house and family underwent several follow-up measure to create a solid information about how the house performed according to the preliminary calculations during the design and development phase [familiens dagbog 2010].

In 2011, Tine Steen Larsen, a researcher from Aalborg University, conducted a separate study of existing low-energy houses in Denmark to create a wider data base for how to improve future low energy buildings. The findings were ''based on the 'Comfort House' and 'Home for Life' projects [Larsen 2011].

In the following chapter, the passive and active house types will be evaluated based on information from the existing studies. Focus will be on the benefits and disadvantages of the two types of low-energy class buildings. The technical, architectural and human behaviour aspects will be described in order to create a solid platform to develop a new low-energy prototype building.

Human behavior

In creating new types of dwellings, the human behaviour element is an important aspect. The human being is a curious creature, which gives cause for the constant development and research in finding better solutions. Humans are always searching out new knowledge to expand their horizons. Even though the human being possesses great urge to find new solutions, almost all people creatures of habit, especially when it comes to their dwelling.

In creating a new type of dwelling, knowledge of human behaviour is crucial to insure a solution that can fulfil the technical demands and provide an attractive and comfortable way of living. The opinion of the test families in the two described projects has been used to improve the design and technical solutions that could create a more attractive dwelling for the Danish families. In the study of how to develop holistically designed low-energy buildings, Brunsgaard's study focused on how to make the new building type more attractive for Danish families. She writes:

'*The homes of the future need to be designed in a way that the occupant can relate to them and live their lives comfortably in them. Therefore, it is necessary to acheive knowledge and experience about the architecture, the life and user behaviour needs in low ener buildings in order to optimise and improve the next generation of low energy houses.*

Previous examples of low energy houses in Denmark have been represented by more alternative and odd looking buildings.... It is believed that the future low energy houses should be something recognizable and attractive and maybe not so different from what the Danish population are used to' [Brunsgaard 2011 page 75].

The Danish sociologist Birte Bech-Jørgensen has conducted many years of study of everyday life. She stresses the need to apply a double perspective.

The double perspective model consists of three elements: the conditions, the management and the everyday life. The first perspective concerns how new conditions of an everyday life can affect the way of living. The second perspective is how people manage the new conditions, an adjustment which itself results in a changed everyday life, the third perspective. Figure 81 illustrates Bech-Jørgensen's model [Bech-Jørgensen 1997].

Research performed by Camilla Brunsgaard and Tine Steen Larsen concluded that both energy and heat consumption of a building can vary considerably from family to family. The low-energy houses, both passive and active, are designed according to a certain behavioural and consumption parameters. Consumption of a low-energy house depends on how the occupants behave and utilize the designed passive features. [Larsen 2011].

The motivation for living in a passive house

Single family house

- Good neighbourhood
- Close to school
- Recreational areas
- Like the idea of passive houses
- Important with space, peace and quietness
- A new house with minimum maintenance
- A larger house outside the city but still close to it

Figure 80, Test families opinion

The motivation for living in a active house

- Curious to try something new
- Test if the welfare of the family life will increase
- The hope for an improvement of the indoor climate and air change
- To live in a home which can provide a healthier climate and more energy to the family

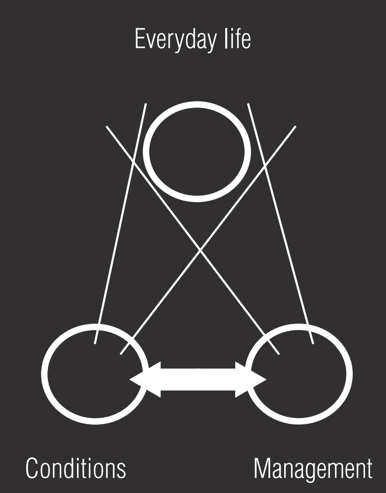
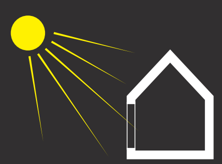


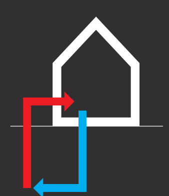
Figure 81, Double perspective

Parameter	Criteria
Space heat demand	Maximum 15 kWh/year per m2 net area
Primary energy demand	Maximum 120 kWh/year per m2 net area
Infiltration, ir change at maximum	0,6 1/h with a pressure difference of 50 Pa

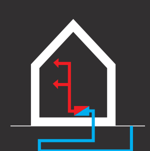
+ Compact building
+ High insulation
+ Air tight



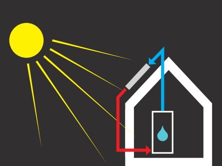
+ Large windows to south
+ Passive air heating
+ Maximum U-value: 0,80 W/m2K



+ Passive heating air by underground ducts
+ Heat fresh air to a temp. above 5 degree



+ Mechanical ventilation
+ Heat recovery over 75 %



+ Solar collector
+ Heating domestic water

+ Energy saving household appliances
+ Low energy refrigerator, stoves, lamps etc.

Figure 82, Passive strategies

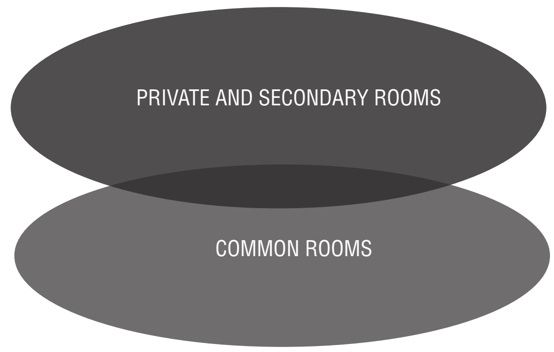


Figure 83, Passive house layout

Passive house

The passive house concept originates from Germany, and the term was defined and developed by The Passivhaus Institut in 1996. The institute was found by the German Dr. Wolfgang Feist [Passive house institue, about us 2016]

The standards developed in Germany cannot be directly applied to Denmark. The Danish tradition for architecture, building techniques and users differ from Germany. Therefore, it has become necessary to develop a Danish passive standard with inspiration from the experience of other countries. In 2008, the company Saint-Gobain Scandinavia initiated the 'Comfort House' project with the intention of creating a Danish passive house standard [Brunsgaard 2011].

The passive house standard is focused on minimising heat loss and maximising heat gains by employing passive design strategies such as integrated solar shading, high insulated walls, windows to the south, etc. [SEI, passive homes] in order to fulfil the German passive dwelling standard. The requirements are listed in figure 82.

All the requirements for a passive certification are illustrated and described in the grey column. All the technical and architectural elements are equally important.

In designing the layout for a traditional dwelling, the focus is on the unmeasurable and measurable daylight, the view and how the different functions in the house should correspond to each other. In a passive dwelling, the layout requires careful consideration of the different function in relation to the heat requirements and use of the surrounding climate to create a less energy-consuming house. A typical layout for a passive house is illustrated in figure 82 [Brunsgaard 2011, page 58]

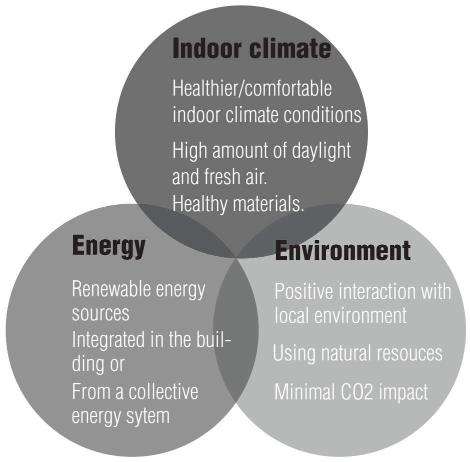


Figure 84, Active house concept

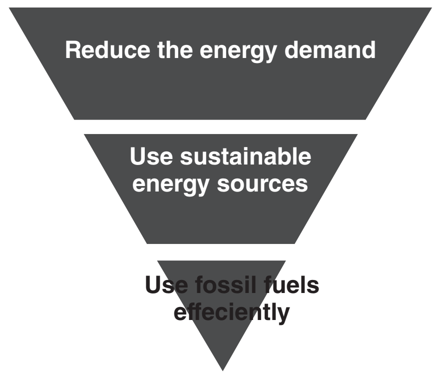


FIgure 85, Trias Energetica figure

Active house

For over 30 years, the main focus on developing low-energy buildings has been on designing passive dwellings with minimal heat consumption. In designing buildings that can meet the requirements of the Brundtland Report not to compromise the needs of future generations, all the stages and decisions of designing a building should be carefully considered, with a focus on minimising materials, energy and heat consumption and carbon dioxide emissions; see figure 86.

In 2008, the Danish company VKR Holding created a new type of low-energy house, the active house, that would have a minimal impact on the environment. The project produced a prototype single family house in Lystrup to test the active house concept on an average Danish family. The active house concept combines both passive and active solutions to the building's design. The active solutions are renewable energy sources such as solar cells, heat pumps, etc. [Lavenergi i flere koncepter 2016]

The general definition of sustainability consists of three main spheres: environment, social and economic [Hvad er bæredygtighed 2015]. The requirements for an active house can be described in an illustration of three spheres: the comfort sphere, the energy sphere and the environmental sphere, see figure 84. The focus is on the interaction between energy consumption, indoor climate conditions and the building's impact on the environment[Panek 2016].

The most optimal sustainable energy design is to save energy. The active house design, orientation and production has been developed to utilise as little energy as possible and to exploit renewable energy sources. The principle from 'the Trias Energetica' figure 85 is being applied to develop an optimal energy saving construction that can generate a holistic design. A holistic design solution encompasses both the technical and architectural solutions from the very beginning to create an integrated design solution that can minimise energy consumption and provide the occupants with a high quality of life. The criteria for an active house are shown in the grey column [Trias energietica 2016].

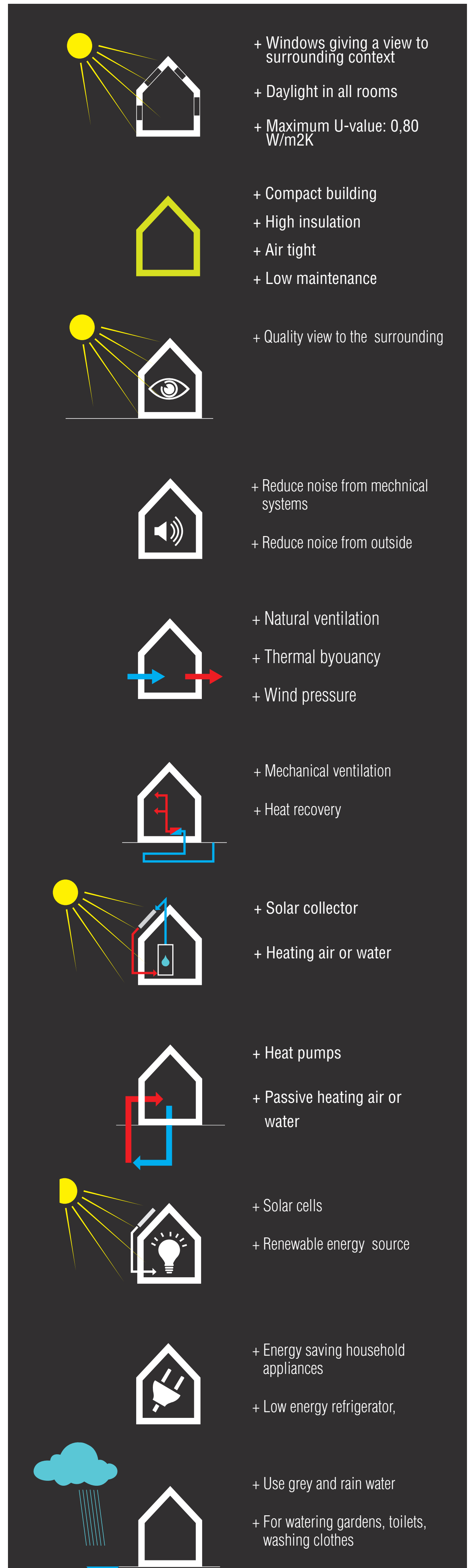


Figure 86, Active house strategies

Passive house strategies and effects on the indoor climate

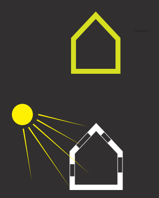
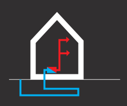
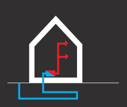
	Technical strategies	Elements	Advantages	Disadvantages conditions	Management	Effect on the occupants everday life
Passive heating 	Exploit heat from thesun Well insulated/ airtight avoid heat loss	Large windows to south	Heat from the sun all year, minimize heat consumption from district network	Large windows to the south can cause overheating during summer	Install curtains to minimize the heat Open windows to ventilate	They feel living in a box because of the curtains The everyday routine has changed
Active heating 	Ventilation air for heating	Heat recovery units in the mech. ventilation system with high efficient	The electricity consumption and installations reduced	Not possible to adjust temp. in the rooms separately Cannot always deliver enough heat in winter	The occupants install curtains to minimize the heat The occupants open the windows to natural ventilate	The occupants wear more cloths
Ventilation 	Ventilated by mech. system winter/ summer		Reduced heat loss with using a closed system	Reduced occupants control Windows not designed to stay open	Hard time to trust the mech. system Psychological feel the air is not fresh	The occupants open the windows to get fresh air

Figure 87, Indoor climate, passive house

Active house strategies and effects on the indoor climate

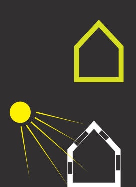
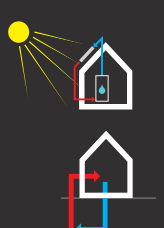
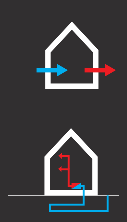
	Technical strategies	Elements	Advantages	Disadvantages conditions	Management	Effect on the occupants everday life
Passive heating 	Exploit heat from sun Well insulated/ airtight avoid heat loss	Windows to all sides, larger to south	Heat from the sun all year, minimize heat consumption from district network	Large windows can cause glare	More frequent use of blinds	Lack of passive heating
Active heating 	Ventilation air to supply heat Solar collector Heat pump	Heat recovery units in mech. ventilation system Solar collector heat the water /air supply of heat	Combination of all 3 elements provide the family with required heat	Require natural cooling during night time due to overheating - during winter can result in dry air	Open windows at night in winter period	
Ventilation 	Natural ventilation - summer Hybrid ventilation – spring/autumn Mech. ventilation - winter		Reduced energy consumption with using a natural resource The system is automatically and adjust itself during the year	Noise from mechanical opening of windows during the night	Overrule the automatic system to feel in control Mostly trust the mech. system. Positive with the amount of fresh air	Learn to control the electronic ventilation system to adjust the climate to their needs

Figure 88, Indoor climate, active house

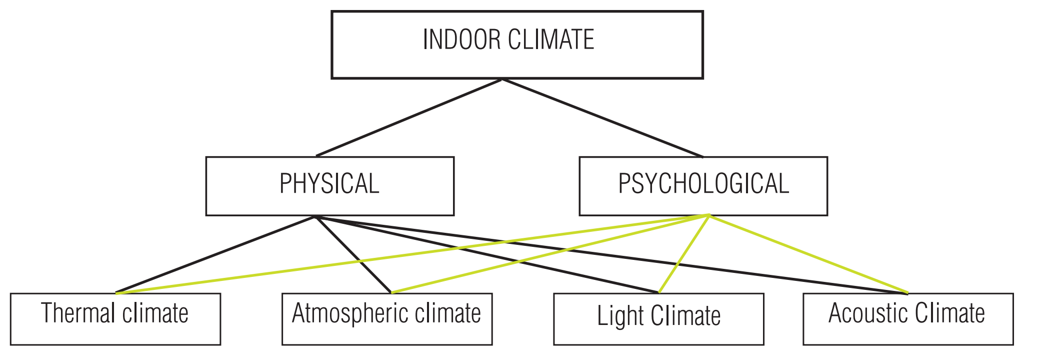


Figure 89, Indoor climate factors

Technical aspects

All the technical elements in a low energy house are related to the conditions of the indoor climate. The indoor climate consists of physical and psychological factors. These factors can be experienced differently from person to person, depending on the individual's psychological state. Conversely, our psychological state can be affect by the physical climate.

The physical indoor climate can in turn be divided into thermal and the atmospheric climate. The thermal climate is related to temperature, while the atmospheric climate relates to quality of the air in the house. Figure 89 shows the various factors that must be considered in evaluating indoor climate conditions [Hyldgård 2001]. In the description of the different technical solutions to both passive and active concepts, 'the double perspective' and parameters of the indoor climate are applied to obtain a comprehensive understanding of the link between technical, architectural solutions and human behaviour.

The technical aspects

- + Use passive strategies
- + Minimized heat consumption
- + Large solar gain with great windows to south
- + High quality of daylight, reduce eletrical lighting

- ÷ Only focused on heat consumption
- ÷ Overheating during summer caused by large windows to south
- ÷ Only applying passive solutions
- ÷ Only using mechnical system to ventilated
- ÷ Not designed to apply natural ventilation
- ÷ Lack of freedom, the windows are not designed to stay open
- ÷ Only heated by mech. system, lack individual heat regulation in rooms

Figure 90, Benefints and disadvantages

The architectural aspects

Plan and interior design

- + Open plan, support gathering the family
- + Interrelationship of the functions of the rooms
- + Modern style
- + Harmony in choice of materials
- + Open kitchen-dining area – more gathering
- + Direct access to bathroom from bedroom

Windows

- + Good daylight because of the large windows
- + Provided with a proper view to the surroundings

Urban

- + Large green areas

Plan and interior design

- ÷ Lack of storage
- ÷ Desire a woodstove to feel home
- ÷ Miss windows in the bathroom

Windows

- ÷ Feel exposed to the public street because of placement and large windows

Urban

- ÷ Miss shelter in the outdoor area

Figure 91. Occupants experience

Conclusion of passive house design

Passive house strategies seek to solve the problem of excessive heat consumption with minimizing heat loss in the envelope and are able to use the internal heat generated by occupants and installations to achieve a minimal heating requirement. The passive buildings in the Comfort House project were designed to stay warm during the coldest month of the year by having large windows facing south. The houses are designed with integrated solar shading devices to minimize the heat gain from the sun during the summer, ensuring a comfortable climate during the warmer months.

In developing the different house designs, the Be10 program had been used to both evaluate the energy consumption and assess the risk of overheating during the summer. The Be10 program is designed to provide an estimate of the building's future energy consumption. The various heating problems that the test families have experienced could have been avoided by using an indoor environment simulator like the BSim. The BSim program can evaluate the indoor climate conditions at both thermal and atmospheric levels on an hourly, daily or monthly basis. The recapitulation of benefits and disadvantages of the passive house design are described in the grey column in figures 90-91 in bullet point form [Brunsgaard 2010].

The occupants in the passive houses experienced a lack of interaction with the passive strategies. All three test families had similar problems with the comfort houses. The heating strategies, using only mechanical ventilation heat recovery to supply heated air to all the rooms in the home, allowed for no adjustment to different temperatures in the rooms.

A solution to this problem could be to install radiators or floor heating, which would add to the energy consumption. The passive houses had all been designed to be ventilated using the mechanical ventilation system and not natural ventilation. The windows and doors had not been designed to stay open, which led to frustration among the test families. The solution could be to integrate natural ventilation strategies in the design of the house.

In some of the houses, the large windows in the living room had been placed facing the public street, causing the families to feel a lack of privacy. This resulted in the families using blinds during the day to create a feeling of own space; during the winter, it could result in a lack of passive heating from the sun. [Brunsgaard 2010].

Conclusion of active house design

The active house's technical and aesthetical strategies are focused on creating a holistic design which includes all three important elements; energy, indoor climate and environment. During its' design and development phase, the 'Home for Life' project had integrated the active and passive solution to obtain a pleasant indoor environment.

The house had been designed to run almost automatically, which has both positive and negative consequences. Using an automatic system, the house can adjust itself according to the set parameters and provide the family with an optimal climate.

However, the automatic system cannot predict human's varying reactions to the indoor climate; hence, the test family would override the system when they wanted more natural ventilation or less sun exposure. The changes in the settings could cause more energy or heat consumption. Figures 92-93 explains the family's opinions.

The active house is designed to ventilate using both natural ventilation strategies and a mechanical system. The natural ventilation system requires no energy consumption and is designed to be used from early spring to early autumn.

During this period, the mechanical ventilation can provide fresh air. During winter, the air is cold and dry. To obtain an optimal indoor environment during this season, the house is ventilated by the mechanical system with heat recovery [familiens dagbog 2010].

Active house

- + Holistic design
- + Integrate technical and architectural solutions from the start
- + Consider energy, context and environment
- + Implemented with both passive and active solutions
- + Designed to reduce both energy and heat consumption
- + Designed to use natural ventilation
- + The windows are designed to stay open when required
- + High quality of daylight, reduce eletrical lighting

- ÷ Can overheat during summer
- ÷ Indoor climate controlled by automatic system

Figure 92, Benefints and disadvantages

The architectural qualities

Plan and interior design

- + Well-designed plan layout contributes to thriving family life every day
- + The dissolved transition between in- and outside create by the interior floor and exterior terrace are on the same level.

Windows

- + High quality of daylight from all sides almost the whole day
- + Narrow frames which do not break the panorama view
- + Floor to ceiling windows, provide create view to surroundings

Urban

- + Large green areas

The architectural disadvantages

Plan and interior design

- ÷ The semi closed atrium to dry clothes all year, takes to long time to dry
- ÷ Lack of storage in the scullery
- ÷ Proper closets in the entre to store winter clothes
- ÷ Lacking proper closets in parent's bedroom

Windows

- ÷ The large window can sometimes provide with too much daylight and the installed blinds have to be used

Urban

- ÷ The family feels exposed to the public street at night time with the large windows placed to the street. They use the blinds to create the feeling of privacy.

Figure 93, Occupants opinions

The conclusion

The aim of this thesis is to develop dwellings that are both environmentally sustainable and can provide residents with a highly satisfying indoor climate. The passive house is focused mainly on reducing heat consumption, which unfortunately, results in unpleasant overheating during the summer.

The active house concept takes a holistic approach, considering how each design and building phase affects the environment, the energy and indoor climate conditions. The active house concept seeks not only to reduce energy and heat consumption in the house, but also to leave a positive footprint on this world.

The technical and architectural features of the house are being simultaneously developed into a coherent house: both active and passive strategies are applied with a focus on the future inhabitant of the house and the environmental and social context. This concept will therefore be applied in designing a new proposal for a single family house in Denmark.

Design parameters

- ★ Placement of windows with consideration to minimize exposure to public areas
- ★ If possible windows in all rooms primary and secondary
- ★ Storage facilities in the dwellings
- ★ High quality of daylight and view to surroundings
- ★ Dissolve transition between inside and outside
- ★ Large green area and private garden
- ★ Shelter in the garden

CH. 2.

Technical detail: Passive/active strategies and climatic design

The following chapter presents a description of a series of applied technical solutions that can both minimise energy and heat consumption in a building and provide renewable energy and heat supply.

The 'climatic design' is a design method that seeks to develop buildings in harmony with the surrounding conditions and create an optimal indoor climate; this will be elaborated later in this chapter.

The two projects described in Chapter 1 centred on low-energy house concepts intended to obtain the same goal: to reduce the consumption of non-renewable energy and offer people a sustainable way to live.

The new sustainable dwellings use active and passive solutions to obtain the goal of reducing the consumption. The most sufficient reduction of energy and heat consumption can be achieved by minimizing the needs, which passive strategies are designed to do.

There are different passive strategies which can reduce consumption for example using the sun to that the building during the winter with placing large windows to south. The active strategies are applied subsequently, so as to supply the building with energy from renewable resources either onsite or off-site.

Passive strategies

Conduction

- Different construction methods of outer wall
- The effect of a green roof and walls

Convection

- Different natural ventilation strategies
- Different placement of the window, linear thermal los

Radiation

- Different kinds of window placement, daylight quality
- Different solar shading solutions
- Different orientation of the house with different window placement, the effects on the indoor climate

Active strategies

- Wind mills
- Heat pumps
- Solar collectors
- Solar cells
- Heat recovery unit

[Jacobs, J-P., 2007]

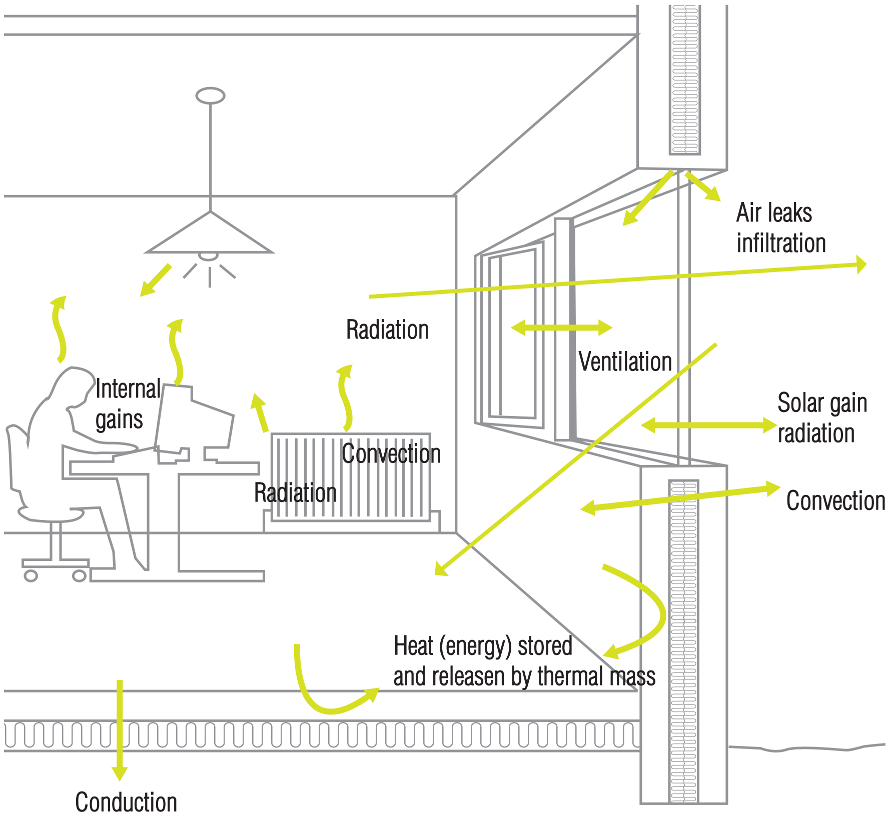


Figure 94, The Energy of heat flow

Climatic designs potential in sustainable architecture

The building industry is constantly seeking out new solutions and techniques for constructing create optimized buildings for people. Some of these methods are truly ground-breaking, while others are several hundred years old.

One of the oldest building methods in the world is climatic design. The method is uses the beneficial elements of nature to create comfortable, energy-efficient and environmentally intelligent buildings. Knowledge about the wind, earth, sun, air temperatures, moisture and of the beneficial effects of plants, are exploited in a climatic design building [Heiselberg 2006]. As Heiselberg states:

'*The desirable procedure is to work with, not against, the forces of nature and to make use of their potentialities to create better living conditions*.' [Heiselberg 2006, page 7]

Climatic design principles are applied to a building's design so as to achieve a high level of comfort for the occupants all year round. To achieve such a building, the location, surrounding context, neighbouring buildings, sun location, wind and air pattern design are all important in the design of the orientation of the building, thus achieving the maximum effect of the present climatic conditions. The design features used to create such a building will, of course, differ according to the climate conditions.

All buildings are exposed to an energy flow, which has a direct relation to the building's energy and heat consumption. The energy of heat flow in a building consists of three factors, also illustrated in figure 94:

- Conduction - also called transmission, is dependent on the thermal insulation or conductivity of a material or construction.

- Convection – the air movement can be controlled through ventilation or infiltration. Infiltration is air leakage in a building's envelope that can be reduced or eliminated by a more airtight construction.

- Radiation – energy from the sun exposure on a building goes through primarily glazed elements; exposure differs with latitude and orientation.

The amount of energy flow and direction through a building can differ during a day, a month, a year and from place to place depending on the internal and external conditions. The chosen construction and materials for a building can determine the amount of energy permitted to flow through the climate screen [Jacobs 2007].

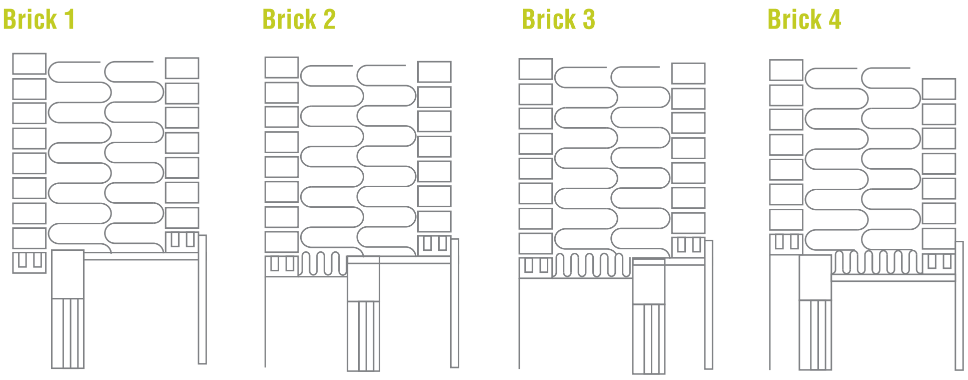


Figure 95, Different window placement in a sectional view of a brick wall

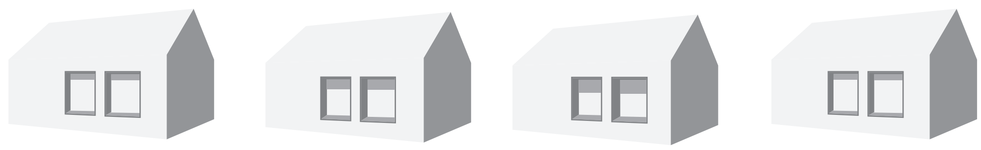


Figure 96, Different window placement in a 3d model

info	Brick 1	Brick 2	Brick 3	Brick 4
Placement	0 mm	115 mm	230 mm	0 mm
Insulated frame	No	Yes	Yes	Yes
Average value of the linear thermal transmittance around the windows with fittings	0,020	0,009	0,008	0,000

Figure 97, Table of window placement in a wall

Placement of windows

Every technical and construction detail in a low-energy house has to be carefully considered to minimise heat loss through the climate screen. Alternative placement of windows in the climate screen contributes to different architectural expressions and different values of the linear thermal transmittance, all of which can affect the energy calculations.

A Danish study has focused on the effect of varying placements of a window in an exterior brick wall. Figures 95-97 shows four versions of a window detail in a brick wall, illustrating the varying placement and insulation methods. The four solutions result in different average values for linear thermal transmittance, in that reduced linear thermal transmittance so as to will also reduce heat loss through the construction.

The placement of the window in the outer wall reflects a technical solution, as described, and the architectural expression of the surface. The traditional solution of placing the window in close connection to the outer wall is intended to maximise the amount of daylight that enters the house and minimise shading from the construction. Danish windows are designed to open outwards, which is related to Danish building traditions and placement of windows. In the solutions shown in Brick 2 and 3 the windows are placed in the insulation in order to minimise the heat loss. However, this results in the window casting a shadow from the construction, reducing the entry of daylight and passive heating from the sun.

This construction principle is applied mainly in warmer countries, such as Italy, where the windows are moved far back to minimise the heat gain from the sun and provide occupants with a cooler climate. The principles are not optimal for Denmark's cooler climate where there is desire for optimized exposure to the sun. The Brick 4 is an updated version of the Danish building traditions with an improved insulation solution [Brunsgaard 2008].

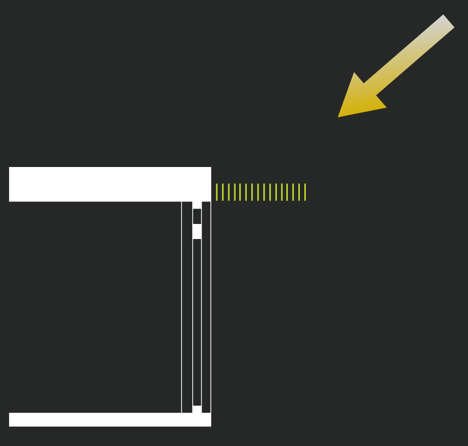


Figure 98, Integrated solar shading

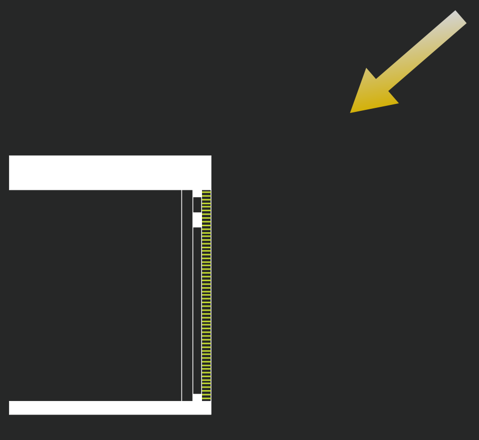


Figure 99, Automatic/ Manual solar shading

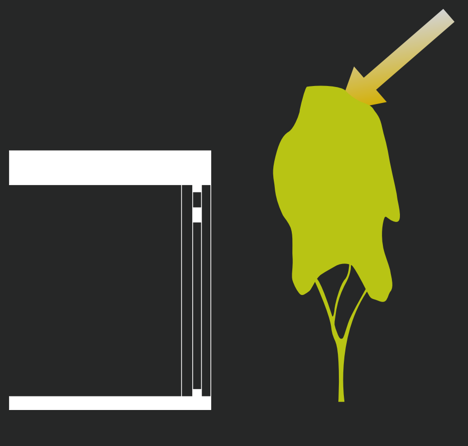


Figure 100, Natural solar shading

Window placement relation to daylight

In all types of houses, daylight is important for creating a pleasant indoor environment for the occupants. In low-energy houses, daylight helps reduce the need for electrical lighting.

The daylight entry can be controlled by applying different window placement to obtain the most desirable and optimised daylight distribution in the entire house. The window placement can differ for each room according to the most optimal results. During construction, four different strategies can be applied:

1. Large windows placed in the vertical climate screen to provide daylight from all possible sides, important to test for overheating risks.
2. Windows placed high in a vertical wall can provide increased daylight quantity far into a room. This high window placement also allows more freedom in the interior design.
3. Windows placed on horizontal or tilting roof surfaces, as skylight can add daylight into deep rooms; placed where it is impossible to insert vertical windows, it can increase the effect of natural ventilation.
4. However, the skylight can result in glare problems, so that precautions must be taken by installing solar shading devices.

Installing glass walls inside a house can distribute daylight from one room to another [Larsen 2011].

Different solar shading solutions

Low-energy houses are designed with large windows facing south. During the summer, the large windows can cause overheating and undesirable glare from the sun. These problems can be solved by using solar shading devices. There are four ways to apply such solar shading elements.

1. Integrated solar shading:

   The construction of a building can be used as an integrated solar shading element e.g. an overhang over the windows. The overhang's length is calculated from the sun's height. The overhang is designed to shield from the high summer sun while allowing the winter sun to enter the rooms. See figure 98.

2. Automatic solar shading

   The automatic shading devices can be integrated into the building's design and become visually attractive elements. With an automatic system, the house can adjust the sun exposure during working hours, when the occupants are not at home, to avoid overheating. The automatic system requires energy and maintenance. See figure 99.

3. Manual solar shading:

   The shading devices consist of adjustable slats and shutters that can be operated manually by the occupants, non-energy consuming devices with low maintenance and reliable. See figure 99.

4. Natural solar shading:

   Green deciduous plants can be used as a solar shading element. The plants can grow over a vertical or horizontal structure, and sunlight can filter through the structure with minimised heating capacity. Strategically planted trees can be used as solar shading in the spring, summer and early autumn. During winter, the leaves are gone and allow the desired winter sun to enter the building. See figure 100. [Larsen 2011]

Active ventilation methods

Natural ventilation

In temperate climate areas such as Denmark, wind factors are used in a building's design to provide natural ventilation. The ventilation has three main primarily functions:

1. Ensure a supply of fresh and clean air that can be regulated according to the occupants' needs.
2. Ensure a high quality of indoor environment and comfort.
3. Regulated venting with fresh supplied air can remove undesired heat waste, polluted air, humidity and cool the building.

The natural ventilation utilises the natural driving forces of buoyancy or wind or a combination of both. Buoyancy is a physical phenomenon and is driven by temperature differences in room and the density of cold and warm air.

A natural ventilation system will often rely on both driving forces, but one of them will predominate. The predominant driving forces will have an influence on the layout and shape of a building and on the ventilation strategies to be applied. There exist three main venting strategies: single-sided, cross and stack ventilation, shown in figures 101-103.

To obtain effective utility of the natural forces in venting a building, the surrounding vegetation can be designed so as to enhance the driving forces and protect the building from undesired wind turbulence.

A study by Heiselberg highlights the main functions of vegetation, as far as an air movement is concerned. These are: wind sheltering, wind deflecting, funnelling and acceleration of air and air conditioning.

The type and layout of vegetation should be included in the site plan, with consideration given to the airflow patterns for the area as well as aesthetic and the environmental factors [Heiselberg 2006].

Mechanical ventilation

Mechanical ventilation can be applied when the natural ventilation strategies are not sufficient enough, which happens in the winter period. All year round, occupants require a supply of fresh air to remove the polluted air and waste heat. Hence, to avoid unpleasant cold and dry air during the winter, a mechanical ventilation system should be applied.

The system can be supplied with a heat recovery unit. The unit is able to both heat up the outdoor air to the required temperature and re-use the heat from the extracted polluted air. The distribution of heated fresh air reduces the building's heating consumption [Stampe 2000].

The Hybrid Ventilation

Hybrid ventilation is a system consisting of both natural and mechanical ventilation strategies. The two types of ventilation strategies can be turned on and off according to the required needs for the residents. Mechanical ventilation with heat recovery will be preferred during the winter in order to reduce heat loss.

During the summer natural ventilation will be the preferred option to reduce energy consumption, with mechanical ventilation being reserved for use only in those rooms requiring air extraction e.g. kitchen and bathroom [Stampe 2000].

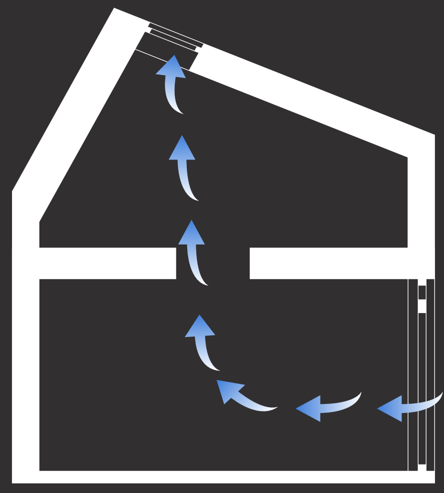


Figure 101, Stack ventilation

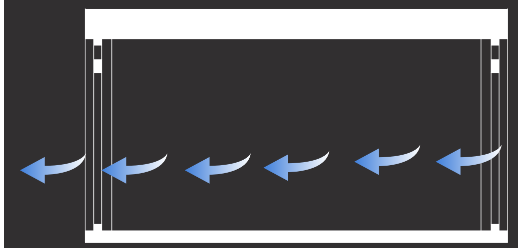


Figure 102. Cross ventilation

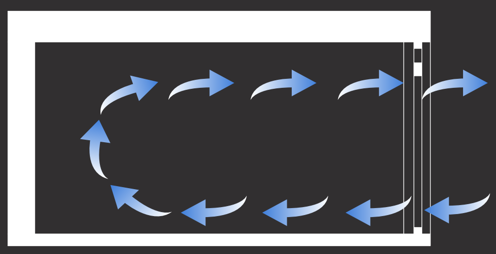


Figure 103, Single sided

Figure 104, Windmills

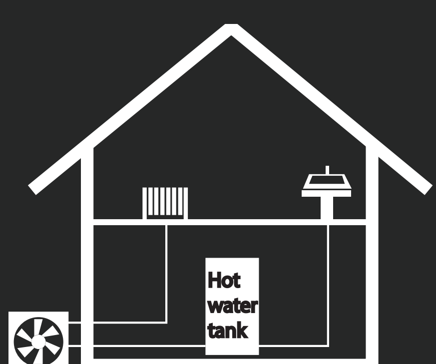


Figure 105, Heat pumps - air to water

Renewable energy sources

For several years, it has been common knowledge that the non-renewable energy sources being consumed every day are being rapidly depleted. The non-renewable energy sources are, for example, carbon-based and organically derived fuel.

If the consumption of the non-renewable energy sources continues unchanged, they will be depleted within the next hundred years, and they are a contributing factor to polluting the earth. The renewable resources are developed to exploit the natural resources, which cannot be depleted and do not pollute the air. Today four different types of renewable energy sources exist that can be applied to domestic buildings [WCED 1987].

Windmills

The windmill is designed to convert wind energy into rotational energy by means of vanes. The largest windmill is approximately 90 metres high. In the production of energy, windmills are non-polluting and exploit a natural non-depleting source. The machine is highly reliant on constant exposure to wind. The Danish coast line's harsh wind conditions are optimal for windmills, See figure 104.

The two types of windmills are: on land and on sea. Windmills at sea are more exposed to constant wind and therefore generate more energy than land-based windmills. In Denmark, the population can buy a share in a windmill and subtract the electricity produced from their yearly household consumption. This type supply of renewable energy source is often used as an off-site energy contributor [Sådan fungerer en vindmølle 2016].

Heat pumpts

The heat pump is a renewable energy source which absorbs energy from a heat source at a low temperature level. The extracted heat is then converted to a higher temperature in a closed circuit system that can supply a house with either hot water or space heating.

The system requires energy to drive the closed circuit system. It can produce heated energy which is typically 2-5 times greater than the added drive energy. There are three different kinds of heat pumps [Sådan fungerer varmepumpen 2016].

Brine to Water: the system consists of two elements: a large amount of pipes placed into the ground and a heat pump inside. The pipes are filled with antifreeze liquid; the liquid is heated by circulated it in pipes in the ground. The output can be used for space heating and domestic hot water [Hvad er jordvarme 2016].

Air to Water: this system consist of two elements: an outdoor element that utilizes the heat in the air and transfers it by a ventilator to an inside unit. This unit transfers the heated water to a central heating system that can supply the house with space heating, floor heating or radiator, and/or domestic hot water, see figure 105. [Luft til vand varmepumper 2016]

Air to Air: the system consists of two elements: an outdoor element placed on the exterior wall of a house and a unit placed on an interior wall. This system delivers heat in the form of heated air, but it is only able to heat the room in which the interior unit has been placed. The system is used mostly in summerhouses [Luft til luft varmepumper 2016].

Solar cells

The solar cells or photovoltaic panels convert the sun rays into electricity. The panels can produce power even during overcast weather, as the panels are activated by sunlight and not by the sun's rays. The production efficiency is dependent on the placement, orientation, angle and of possible shadow casting. See figure 106.

The optimal placement is free standing, with the unit positioned at a 45 degree angle directly to the south, without any shadow. The panel can be installed either as an integrated part of the building's envelope or it can be freestanding. There are three types of solar cells [Sådan fungerer solceller 2016].

Mono-crystalline cells: have a high efficiency of electricity production due to the dense construction of the silicon block surface. The panels are often grey or black with a uniform surface. Their efficiency is 14-16% [Monokrystallinske solceller 2016].

Poly-crystalline cells: the panel consists of silicon crystals that give it a bluish colour, today it can delivered in a variety of colours. The efficiency is 12-14% [Polykrystallinske solceller 2016],

Thin film solar cells: the cell's surface has a homogenous black colour and is translucent. They can be applied on windows, railings or other surfaces. The efficiency is 6-10% [Amorfe eller tyndfilmssolceller 2016].

Solar collectors

The solar collector is an energy resource designed to transform the sun's energy into heat. The system consists of an outside unit and an inside unit. The outside unit contains the solar collector panels, which are filled with antifreeze fluid that gets heated by the sun's rays. See figure 107.

The heated liquid is then transferred to the inside unit, which acts as a heat exchanger. The heat exchanger can be attached directly to the central heating system or connected to a storage tank. The solar collectors can only contribute to the building on which they are placed [Solfangere og teknik 2016].

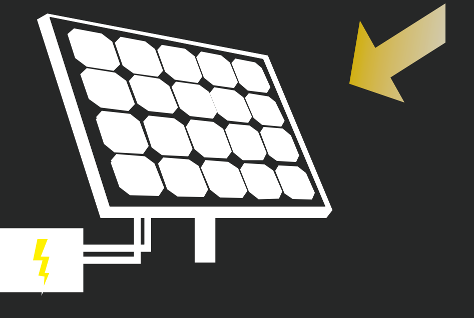


Figure 106, Solar cells

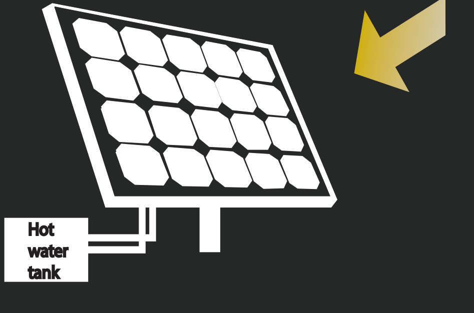


Figure 107, Solar collectors

Comparing new sandwich element with traditional				
Minimum requirement for W/m2K, New buildings	BR10 0,15 W/m2K	BR15 0,12 W/m2K	BR20 0,08 W/m2K	BR25 0,06 W/m2K
Sandwich element in CRC with rigid PUR insulation	245 mm	280 mm	340 mm	450 mm
Traditional sandwich element with stone wool	450 mm	520 mm	620 mm	820 mm

Figure 108, table for Connovate sandwich element

Concrete

In 2008, three Danish firms joined together in a collaboration called Connovate to develop a new sandwich element of compact reinforced composite. The three firms were the cement manufacturer Contec, the concrete element factory Confac and the architectural firm Arkitema. In 2010, Ambercon (Danish manufacturer of concrete- and façade elements) took over for Confac. The project was sponsored by Real Dania.

The sandwich element consists of a front and back plate of compact reinforced composite with a core of PUR insulation. By using compact reinforced composite (CRC), the thickness of the front and back plates of the wall can be reduced by up to a third. The plates are 30 mm thick, which leaves more spaced for insulation. The sandwich elements can be delivered as non load-bearing and load-bearing walls with rib construction in steel in the rear wall. The front and back plates in the wall are connected with a wall tie similar to that used in brick walls. In developing the montage system of the elements, the focus was also on totally eliminating thermal bridges [Andersen, 2010].

In countries like Denmark, where housing taxes are calculated based on the dwelling's outer measurements, the slender construction gives benefits with an increase in the habitation area. This makes it possible to accommodate the strict energy requirements without increasing wall thickness. In 2010, The Danish architect Karsten Bro from Connovate explained the benefits to the technical magazine Ingeniøren: '*If you build an ordinary single family house on 150 m2 with our elements, for instance, then you will have been given an extra children's bedroom, because the walls do not need to be so thick'* [Andersen 2010, para. 8]

Connovate delivers the sandwich elements in different wall thicknesses according to how low the U-value must be. The new develop sandwich elements thickness is approximately 45% slender than the traditional wall to reach the required low U-value. Figure 108 illustrates the different possible sandwich element thicknesses compared to traditional sandwich elements with stone wool thickness [connovate.dk/sandwich-elementer, 2015].

To accommodate the requirements of clients, the sandwich element can be provided with different texture treatments, surface structures and in a range of colours to achieve the desired facade expression [Connovate, æstetik 2016].

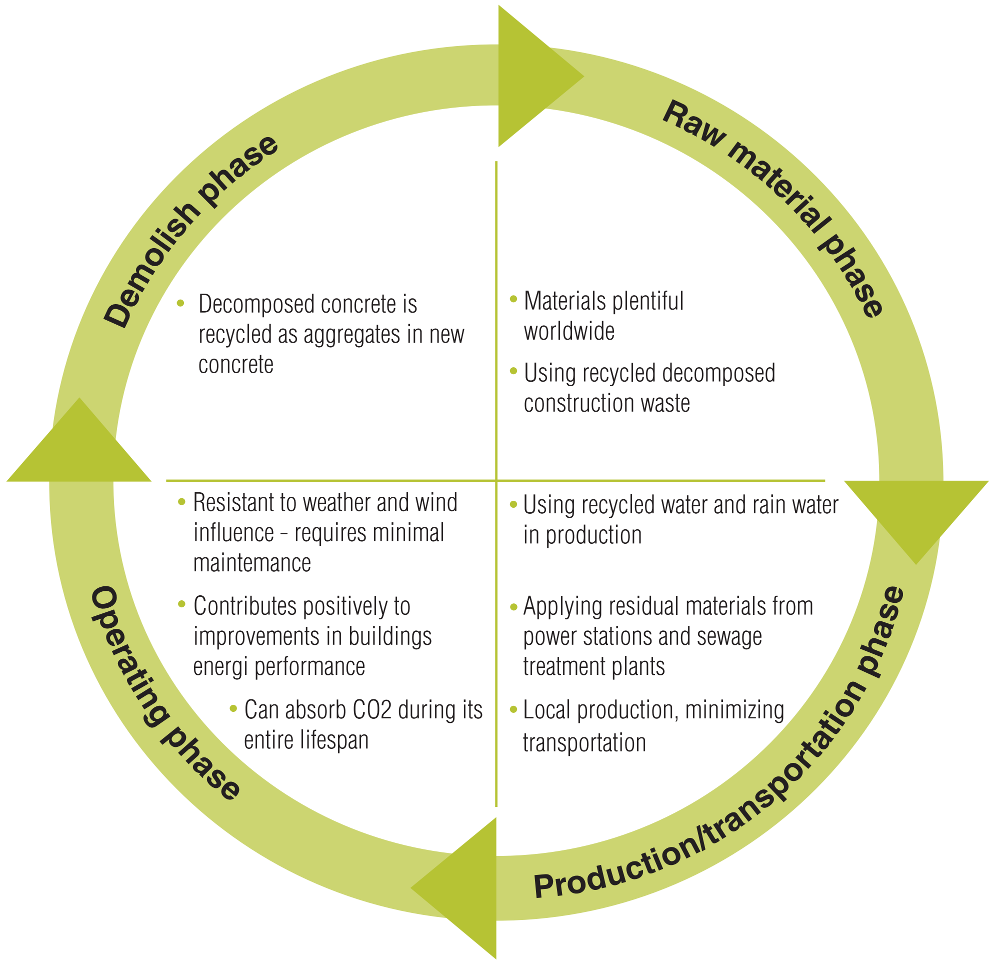


Figure 109, The environmental benefits of concrete

The building system has been tested in two low energy building projects. The first project was a single-family house placed in the Danish village of Tranbjerg. The project was designed and built as a co-operative venture between Dansk Boligby A/S, Brabrand housing association, Arkitema, Ambercon and Contec and sponsored by Real Dania and the High Technology Foundation. The house, called 'Villa Vid', is a vision of a new building era with no thermal bridges and thin exterior walls [Connovate Building, 2016].

Sustainable info about CRC

The sandwich element produced by Connovate uses the CRC concrete to achieve a slender plate in the front and rear of the wall element. The slender concrete plates increase the amount of space for insulation. The people behind the development of the slender sandwich element focused on reducing the environmental impact by reducing the volume of carbon dioxide emissions in manufacturing, transport and assembling on site, see figure 106.

Due to the slender front and rear concrete plates, the material consumption and weight of the total sandwich element is reduced compared to a traditional element. Waste products are used from concrete production, such as coal combustion products and glass fibres. The slender light-weight elements reduce carbon dioxide emissions during transportation and the simple montage system of the wall reduces construction time on the site [Andersen, 2010].

PUR-insulation

Between the slender concrete plates, a high rigid polyurethane-based (PUR) insulation is placed. This insulation material has a closed cell structure and a high cross bond density that results in good heat-resistance, a great compressive strength and excellent insulation capability.

Due to the cell structure of the PUR insulation, the material does not absorb water, in contrast to other widespread insulation materials. Moreover, in applying the insulation material, the exterior wall has no need for windproof layers due to the fact that PUR is wind tight . The material is known for its very low thermal conductivity, as low as 0.022 W/mK. Figure 109 illustrates a comparative study performed between the abilities of stone wool and PUR insulation [Bæredygtighed og polyurethanisolering, 2010].

Terraced house

+ Possible interaction with neighbours
+ Garden, Private space
+ Minimized material consumption pr m2
+ Minimized heat and energy consumption pr m2
+ Minimized maintenance of house
+ Minimized maintenance of garden
+ Central placed in relation to
    - Transport network
    - Cultural activities
    - Groceries
    - Institutes for children
+ Minimise use of a car and promote bicycling and walking
+ Playground placed in the community, parents can watch their children playing from the private gardens
+ Less expensive

÷ Noise from neighbours
÷ Minimized m2 pr person
÷ Regulations for maintenance and appearance
÷ Often only windows to two sides e.g. east and west

Figure 110, Terraced house

Single family house

+ Distance to neighbours
+ Large garden
+ Feeling private space
+ Large indoor spaces
+ Feeling of individuality
+ Windows to north, east, south and west

÷ High maintenance of house
÷ High maintenance of garden
÷ Minimal social possibility with neighbours
÷ High material consumption
÷ High heat and energy consumption
÷ Required high use of a car
÷ Expensive dwelling

Figure 111, Single family house

CH. 3.

Dwellings

Single family house versus Terraced

The development of housing typology in Denmark through the last century has resulted in three main categories: single-family house, terraced house and apartment buildings. Each type addresses different stages in people's lives and their economic possibilities. Apartment buildings are often placed in or close to larger cities and attract young singles or couples, providing them with an economical dwelling with the possibility for an active social life.

When young couples have children, the suburbs become a preferred place to live, as they are dominated by single family houses. The single-family home neighbourhood provides families with a child-friendly environment far from the city and with their own private garden. The terraced house has for a long period of time been the dwelling of choice for a family that could not afford a detached, single-family house.

This typology also attracts people who desire a dwelling with a low required maintenance, a manageable garden and a more socially designed neighbourhood. The economical, sustainable and social benefits of terraced houses are considerable, and through this chapter, the typology will be clearly defined and the features described [Kristensen 2007].

Definition of terraced house

The terraced house is a compact dwelling that combines the features of the more economical apartment and the green space from the single-family house. It is a low rise dense building placed in a row of identical units with private gardens, often located in a family-friendly environment. The housing is often designed with one to two floors and in some cases up to three. The terraced house can also be called a town or a row house. Figure 110 shows the advantages and disadvantages.[Schittich 2006]

Sustainable qualities

In a comparative study of the three main typologies, environmental impacts regarding heating and material consumption show the terraced house to lie between the apartment building and single family house. The compact row-type housing units are often found in close proximity to public transportation networks and required daily facilities, thus reducing the necessity to own a car [Marsh 2000].

In Denmark, the single-family house is the preferred dwelling for families with children, as it provides a family with a large private garden, a spatial dwelling with all the required functions and often placed in connection with bicycle paths to kindergartens and schools. Figure 111 shows the advantages and disadvantages.

Families who cannot afford a single-family house in the suburbs have a tendency to move further away in order to find a house within their budget. Unfortunately, this results is the family becoming dependent on private car transport for commuting, as cheaper houses tend to be further away from public transportation networks.

Terraced housing is an optimal economical and sustainable solution for these families. Unfortunately, this type of dwelling has been overlooked because the gardens are often small and cannot compete with the spatial qualities of the single- family house [Schittich 2006].

Terraced house historical development in Denmark

The basic principle behind the terraced house evolved several hundred years ago. It was developed to create cheap accommodations for workers placed in the dense cities. The typology had its breakthrough in Denmark in the 1920s when the architects began to find the compact cheap dwelling interesting.

1920th

In 1923, the architects Thorkild Henningsen and Ivar Bentsen designed the famous 'Hill houses' at the foot of the Bellahøj area in Copenhagen. The building complex consists of 171 terraced houses placed in 12 lengths of six double rows. There are nine different versions, all constructed with two floors.

All the housing units have been erected with smooth red and yellow brick walls and with a red saddle roof. The dwellings were designed to allow a working class family the possibility to become a homeowner with a private garden. By the Second World War and afterwards, this became an attractive economical dwelling for the working and middle class in Denmark [Bendsen, 2013].

1950th

In the 1950s, architects took a new approach to the terraced house. The layout became more dynamic and dispersed. In the 1950s the Danish architect Arne Jacobsen became interested in dissolving the traditional building's shape. Shapes and surfaces were pulled from each other and reorganized in a new composition, and the traditional saddle roof became an inclining surface.

In the Søholm II terraced house project, erected in 1952, the architect demonstrated a new development of this typology. The traditional long uniform rows had been pulled apart and the dwellings created a dynamic movement. The houses were constructed with two stories, with light yellow brick exterior surfaces. They were designed and placed to optimize the view to the Øresund Strait [Olsen 2002].

1970th

In the 1970s, Denmark experienced major shortages of housing facilities for the continuingly growing population. This resulted in the construction of architectural poor, uniform, industrialized apartment buildings. The youth of the society created a rebellion against the industrialized concrete apartment buildings by creating a new, more social dwelling.

In 1971, the Danish architectural firm Vandkunsten developed a new dense housing facility that provided residents with a social community in a more green and healthy environment. The project was called Tinggården 1 and was inspired by the red Swedish tree houses. The project consisted of 12 'family groups', each consisting of 12-18 apartments placed around a square.

The size of the apartments varied from one to six rooms. Each family group had its own attached community house with the possibility of taking meals or enjoying social activities. The dwellings were constructed 1-2 stories, with exterior walls covered in a warm red wood surface [Tinggården 2014].

In 1973, the oil crisis struck Denmark and resulted in a new ecological architectural movement to create low energy and low heat-consuming dwellings. The passive solar heating became a new design parameter. In 1989, the firm Vandkunsten created a wining solution in the architectural competition 'The futures terraced houses'. The project Egebjerg in Ballerup consisted of 28 terraced houses of 1, 2 or 3 floors.

The houses were designed to exploit the free heat contribution from passive solar heating. The traditional layout of a terraced house from the 1920s had been reintroduced, the dwellings from Egebjerggård project were placed in a long uniform row. [Egebjerggård, Ballerup 2016]

1990th

In 1996, Vandkunsten developed yet another ecological terraced house project, the 'Eco house 99'. The dwellings were developed so that they could more efficiently exploit the natural heating resources from the sun for both heating and energy consumption.

The layout of the buildings was designed according to local climatic conditions to create more efficient low energy buildings. The exterior expression of the dwellings was altered to accommodate climatic conditions and exploit the free resources providing a family with a sustainable home [Økohus 99 2016].

112, Hill houses

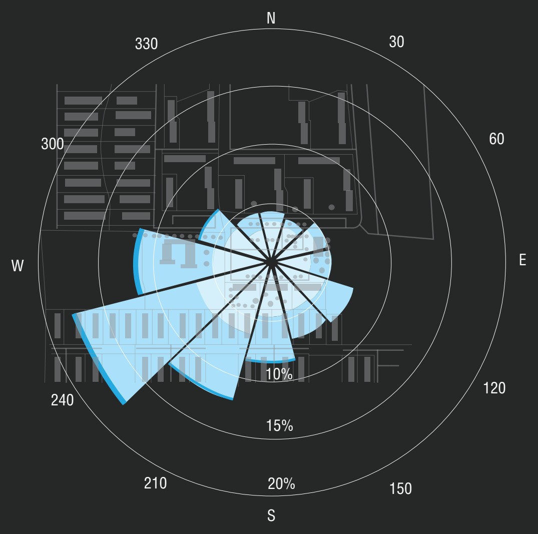
Figure 113, Søholm II

Figure 114, Tinggården 1

Figure 115, Egebjerg

Figure 116, Eco house 99

Wind on site, winter



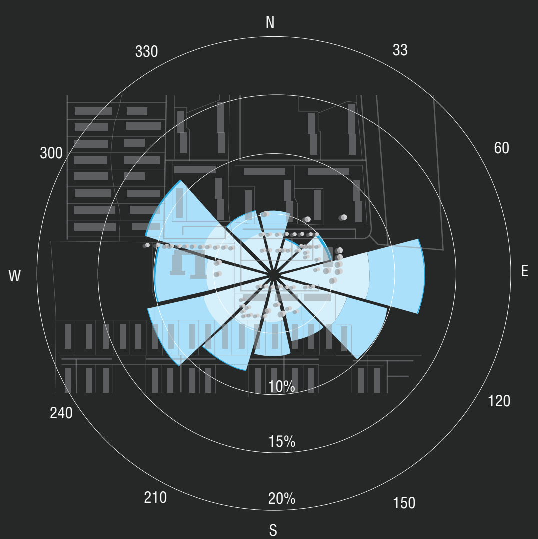
0,3-5,4 m/s

5,5-10,7 m/s

> - 10,8 m/s

Figure 117, Winter wind rose

Wind on site, summer



0,3-5,4 m/s

5,5-10,7 m/s

> - 10,8 m/s

Figure 118, Summer wind rose

CH. 4.

Weather conditions and local plan for the site

Weather conditions typically change from one climate zone to another. In applying climatic design methods successfully, the knowledge of the building site's climate conditions are crucial. The following section presents the characteristics of today's Danish climate, an analysis of the site's climatic conditions and Taastrup municipality's local plan for the site. The chosen location for this project is located in the town Taastrup, located on the north east side of Zealand. The town is only approximately 20 kilometres from the Danish capital Copenhagen.

Climate registrations, wind

Throughout the world, houses are being designed and constructed differently. However, the dwellings retain the same primary objective: to create a shelter that can protect humans from changing weather conditions all year round. Both primitive and high tech dwellings have the same objective: to create shelter. They have been developed to cope with the worst local weather conditions, whether they be extremely high summer temperatures or extreme cold winter conditions.

This project aims to create an optimal dwelling placed in Denmark. The designed dwellings should be capable of exploiting the natural resources from the local surrounding climate. Countries placed between the Equator and the poles are placed in a moderate moisture climate zone; Denmark is one of these. The Danish climate is categorized as a temperate coastline climate zone due to the country being surrounded by ocean.

With its close proximity to the ocean the Danish climate is influenced by harsh wind, frequent rainfall, changeable weather, short cool summers and mild winters. Buildings placed in this climate are designed to protect the residents against the heavy rainfall and harsh frequent windy weather.

Dwellings in Denmark are built to withstand the harsh weather conditions, exploit the limited sun exposure and provide a warm cosy solid dwelling for the residents. The frequent rainfall has led to building styles characterised by high constructions, eaves on the roofs and exterior walls often made of solid material brick [Albjerg 2008].

The wind conditions in Denmark cannot be described as one constant wind from, say, the west or south-west. Danish wind conditions are variable between the local typographic areas. The wind direction can be changed by the local built up area, such that terraced houses and larger apartment blocks can force the wind to locally follow the buildings' longest surface, resulting in a change in wind direction. The change of seasons has a great influence on the wind, In Denmark, the winter season is often dominated by strong winds from the west and southwest, and during the summer, winds come from the east and west

The site is placed in East Zealand, some distances from the coastline, in a local dense residential area with buildings of one to three stories. The figures 117 and 118 shows the approximate wind conditions on the site during summer and winter. The site is sheltered from the harsh wind due to the surrounding trees and buildings while also exposed to some wind from the east, south and west. One of the elements of designing an active house is that the surrounding context makes it possible to utilise the wind as natural ventilation in the house.

Figure 119, Bright surface

Figure 120, Mat surface

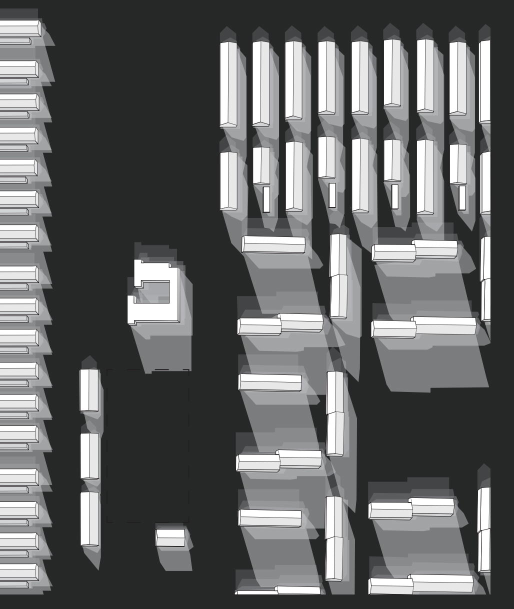


Figure 121, June from 08.00-18.00

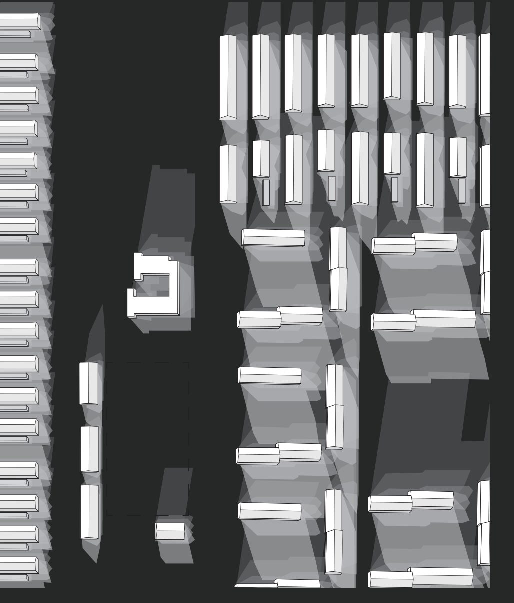


Figure 122, March from 08.00-18.00

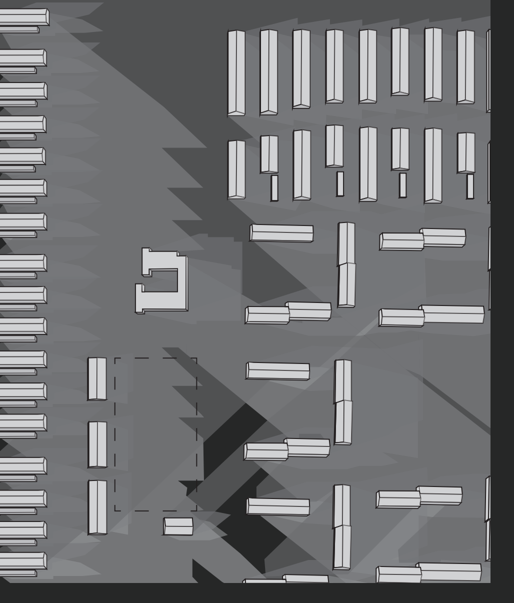


Figure 123, December from 10.00-16.00

Climate registrations, sun

The altitude of the sun in Denmark differs from season to season. In winter, the sun reaches an altitude angle of only 12 degrees; in spring and autumn it rises to an altitude of approximately 38 degrees and in summer the sun reaches a maximum altitude in Denmark of approximately 58 degrees [gaisma 2015].

The changing altitude angles result in different shadow casting during the day and during the changing of the seasons. The winter and summer conditions for the site are shown in figure 121-123. The low altitude of the sun in the winter at afternoon can result in long shadow casting from the surrounding buildings, as shown in figure 121.

The site is exposed to a high amount of sun and reduced shadow casting due to low rise buildings to the east and the south, the three-story-high buildings are favourably placed to the northwest and north orientation and do not result in reduced sun exposure. The site can subjectively be experienced as a rich sun-exposed site with the possibility of exploiting the favourable terms to create light and attractive dwellings. Knowledge of shadow casting conditions and altitude of the sun during the year on the site allows for the designing of dwellings that fit local conditions.

Designing after quality of daylight: The sunlight can be divided into three groups: the diffuse skylight, the reflecting light and daylight. The diffuse skylight is used to determine the daylight factor; the overcast sky breaks the direct sunlight into a soft diffuse light. The light reflects on a building's surfaces and spreads into multiple directions, called reflecting light. The daylight consists of the contribution from the diffuse light, reflecting light and sunlight. The daylight is dynamic and varies through a single day and during the entire year. It is a constantly changing element [Kongebro 2012].

The daylight experience on a location is not only a result of the sun directly, but also a product of how well the light can reflect on the surfaces of the surrounding buildings. The reflection of a building's surface can have a huge impact on the daylight conditions on interior and exterior spaces. The appearance and materials choice of a surface have a great influence on the surrounding buildings' daylight.

Studies have shown that a bright surface has a poor reflecting quality, whereas a matte surface can increase daylight quality by reflecting the sunlight in multiple directions, see figures 119-120. By exploiting the surrounding contexts, the daylight inside a dwelling can be increased, which can reduce the need for electrical lighting. With the knowledge of the sun exposure on the site of the project, the information will be used to increase daylight quality in the dwellings and in the urban space [Kongebro 2012].

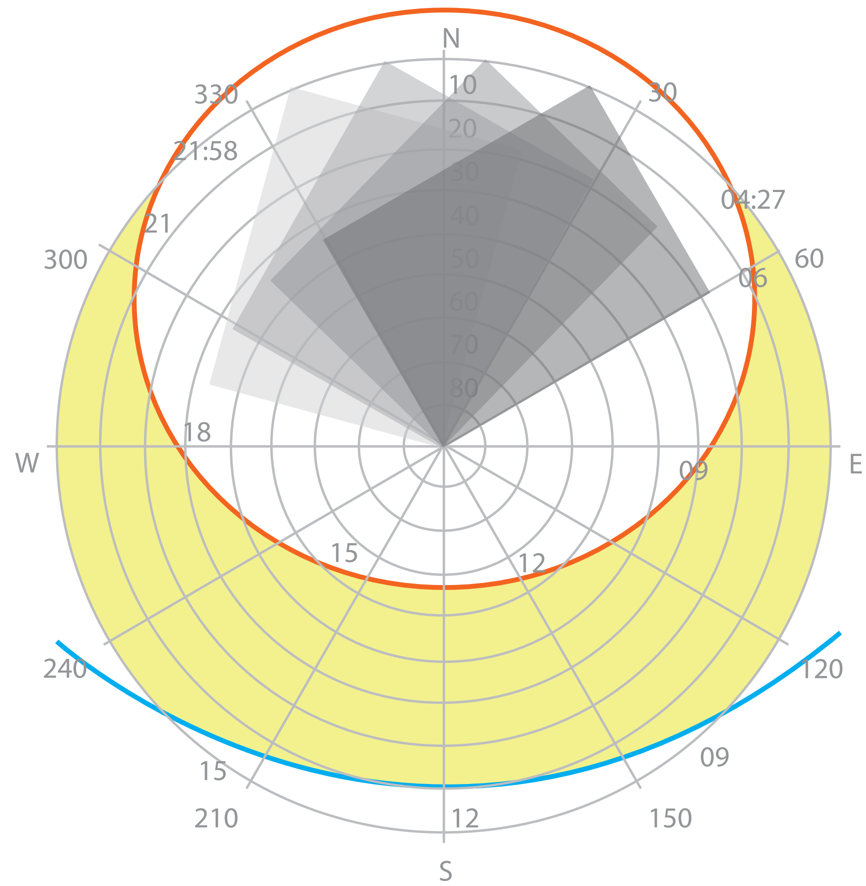


Figure 125, Solar diagram

Orientation of the houses, study

In Denmark during the summer, the sun rises around 04:30 in the morning and sets around 22:00 in the evening. In the winter period months, sun exposure is greatly reduced: from December 1st to about January 15th, the sun rises at about 08:30 and sets at 15:30.

In the Nordic countries, sun exposure is highly appreciated due to the minimal exposure. Therefore, residential buildings should be designed in a way to obtain the maximum amount of afternoon sun in the living room in the winter in order to generate passive heating and psychological wellbeing. During the summer, residents should able to enjoy their dinner on the terrace during the hours of 18.00 to 20.00, when most Danish families take their evening meal.

Figure 125 shows how the sun moves over the year. The centre of the diagram shows a house oriented at four different angels: 15, 30, 45 and 60 degrees from north. To achieve maximum afternoon sun exposure, in the living room during the winter, the house should be orientated to 30 or 45 degree to the north. To achieve optimum evening sun exposure while eating dinner on the terrace, the house should be orientated 45 or 60 degree to north, thus allowing the family to sit outside in the garden and enjoy their dinner in the warm evening sun.

The angle of the houses is not only decided by the sunlight exposure in the dwellings but also determined by how well the solar cell panels of the roof can produce electricity. The difference between how the house is angled according to its production of electricity by use of solar cells is determined by using of an Excel spreadsheet. The results of this calculation are shown in figure 124.

The effect of the different orientations on the generating capacity of the solar cells is tested using a 45 degree sloping roof covered with 40m2 integrated solar cell panels with a 75% efficiency factor. The house's roof is angled toward the south in one calculation and the southwest in the other. The difference between the two orientations is merely 6.5%. Therefore, all the houses will be oriented 45 degrees from north so as to insure proper daylight, optimal evening sun and efficient production of sustainable electricity.

Solar cell production

Type: Mono crystalline

Area: 40 m2

	Vers. 1.	Vers. 2.	Vers. 3.	Vers. 4.
Slope of roof degree	45	45	20	20
Orientation	South	South -West	South	South-West
Efficiency %	15	15	15	15
System factor	0,75	0,75	0,75	0,75
Total kWh	5233	4891	4936	4914

Figure 124 Solar Cell production

Determing the percentage of buildings on site

The focus of many terraced housing projects today is on maximizing the amount of house on a site so as to increase profit. As a result, the surrounding urban context and landscape may be overlooked or ignored.

There is a fine line between optimizing the number of possible houses on a building site and creating an urban context with a high quality. In the decade from 1960 to 1970, architects focused on how to integrate the terraced house into the surrounding landscape as was the case with Sjølundsparken in Hellebæk (see case study 4 on page 110).

Today, these houses have become popular among Danish families. Urban projects such as Sjølundsparken and the Kingo houses have a building percentage of ca. 15-20 % of the ground area. See figures 126-127.

The more recent terrace houses projects, such as Lærkehaven II from 2012, have a building percentage as high as 35% of the ground area, see figure 128. The houses are placed extremely close together, with no consideration for green spaces between them. The spaces between the recently built terraced housing projects are often used for carport and small gardens.

The current project will be developed with a focus on creating a high quality of green spaces between the buildings so as to enhance social interaction that can meet people’s expectations and maintain an effective building percentage.

KINGOHUSENE, HELSINGØR

Size of site	:	52.000 m2
Amount of buildings ground floor area	:	6.000 m2
The percentage of buildings on site	:	11,5 %

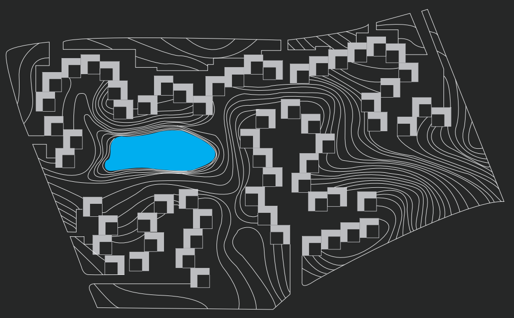


Figure 126, Kingo houses

SJØLUNDSPARKEN, HELLEBÆK

Size of site	:	43.500 m2
Amount of buildings ground floor area	:	8140 m2
The percentage of buildings on site	:	18,7 %

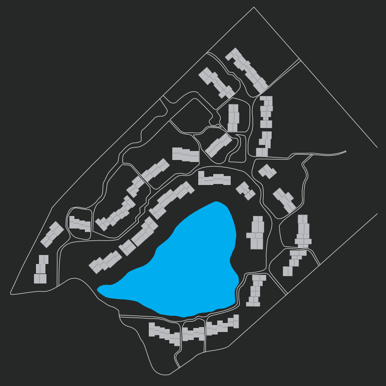


Figure 127, Sjølundsparken

LÆRKEHAVEN II, LYSTURP DK

Size of site	:	5.000 m2
Amount of buildings ground floor area	:	1.760 m2
The percentage of buildings on site	:	35,2 %

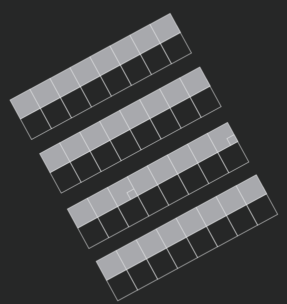


Figure 128, Lærkehaven II

General regulation for the site

Number of dwellings	:	68-70
Gross area	:	9576 m2
Max. building %	:	65 %
Max. floor	:	2 - 3
Max. height of roof	:	11,50 m
of the roof		
Roof types	:	Pointy saddle
Buildings app.	:	Slender
Facade orientation	:	East and West
Main accesses	:	Connected to internal streets
Sheeds	:	max 7 m2

The roof of the buildings shall appear

Inclination of roof	:	70 to 5 degrees
Coating of roof	:	Roofing felt or Plates of zinc, aluninium or steel plates or Dark grey colur
Allowed install	:	Solar cells

Access and parking

Access road	:	parking area entrances connected to the main road in the area
Parking spaces	:	1 ½ parkering space pr house
Handicap spaces	:	5
Larger cars spaces	:	3

Appearance of the houses

The facade of the buildings shall appear

Facade app.	:	Traditional masonry, Light facade wood dressing or Thin plates of zinc, alu. or steel plate or Combination of wood and steel
Brick:	:	Red or yellow nuances
Wood:	:	Coating transparent
Steel plates	:	Natural colours, Thin plates of zinc, aluminium or steel plates

Figure 129, Local plan

Conclusion on the municipality regulation

According to the Høje Taastrup Municipality, regulations regarding the development for residential dwellings on the previous Rønnevang centre site should be followed. The municipality's goal is for the city to have a sustainable appearance. Hence, if the designed project can document positive solutions that might deviate from municipality regulations, the municipality would consider making changes to promote sustainable development. The municipality's regulation for the site is outlined in bullet point form in figure 129.

The project will be designed to fit the surrounding context and should not become a disturbing element for the existing residential buildings. The regulations for maximum height of 11.50 meters will be followed in order to create dwellings appropriate to the local context.

The regulation dictates 68-70 dwellings on the site. This project plans for the construction of approximately 30-40 dwellings on the site. The exact number of dwellings will be determined by the final design, and the developed urban context to create an attractive neighbourhood.

The orientation of the facades, with windows and materials for the surfaces and roof. will deviate from the municipality regulations due to choice of materials. The orientations of the house will be determined by the most optimal solutions for a comfortable indoor environment, sustainable solutions and architectural expression. The materials for the project will also be determined by how well they contribute to the existing context. The dominant building material in the area is yellow and red bricks, the new nursing home have dark grey zinc plates, and some single-family houses will have white boards on their facades.

The regulations for 1.5 parking spaces per house will be followed. One of the aims of this project is to reduce the focus on car use. Therefore, parking areas, instead of being a part of the urban landscape design, should be placed in an underground parking facility [Lokalplan 1.74, 2012].

Design parameters

Low energy house

- Active house concept and climate design method
- Integrated passive strategies
  - Natural ventilation
  - Solar shading
  - Solar heat gain
  - Vegetation
  - High quality of daylight
- Integrated possible active strategies
  - Solar cells
  - Heat pumps
  - Mechanical and hybrid ventilation
- Primary energy frame:
  - 2020 [20 kWh/ m2 year]
- Secondary energy frame:
  - Zero energy house [0 KWh/m2 year]
- 30-40 terraced houses on site
- 2 or 3 stories houses

Dwellings

- 1,5 parking space per house, underground facility
- Each house has a shelter for bicycles
- Choice of materials according to aesthetics and affect on the energy frame and indoor environment
- Daylight
  - Windows in all rooms primary and secondary
  - Windows placement with consideration to minimise exposure to public areas
  - High quality of daylight and view to surroundings
- Dissolve transition between inside and outside
- Dwellings with and without private gardens

Urban spaces

- Large green urban area with playground for children
- Possiblity for social gathering
- Internal path system between the dwellings

Conclusion of the analysis

Architects today have an increased task in designing dwellings. Before the oil crisis in 1973, architects could focus on creating dwellings with a high architectural quality and connecting the surrounding landscape and dwellings. Today, architects can no longer focus solely on the aesthetic appearance, plan layouts and functional values in designing dwellings.

Danish building regulations have increased their focus on incorporating technical aspects such as saving energy and reducing heat consumption. Quality of the indoor climate is now a priority and regulations now require that heating and energy consumption should be minimized. The demands have been tightened for each of the major building classes.

Since the 1970s, new design solutions for sustainable dwellings have been developed. I have analysed two of the most recent and frequently used design methods for the low-consuming dwelling: the passive and active houses.

On the basis of my analysis, the method to be used in this project is the active house. The active house method takes a holistic approach by including both the technical and architectural aspects into every design phase.

The method requires awareness of environmental, economic and the social aspects. By being aware of all the possible passive and active strategies that can be implemented in the design, a more holistic solution can be achieved. In developing a holistic design, architects must become familiar with the future residents' desires and behaviour. Extensive studies have been performed on how the families behaved and perceived the dwellings. In developing a low-consumption house, satisfying the future residents' behaviour will have a crucial effect on how well the dwellings perform. The lessons learned from mistakes and successes in earlier projects such as 'The Comfort House' and 'Home for Life' projects, will be used in this project to develop a new approach to the design of a sustainable dwelling.

The passive and active strategies that can be implementing in a house to insure a pleasant indoor climate and low consumption of energy and heat have been studied. The passive and active strategies listed below will be integrated early in the design process. The study performed on the orientation of the house based on solar cells and achieving a proper daylight through the day will also be used. Hence, all the houses will be placed 45 degrees north.

The aim of this project is to develop sustainable and low-consumption dwellings that can compete with today's popular single-family house. The project will be inspired using data gathered from both low and dense residential housing projects e.g. Sjølundsparken, and by analysing how the architects in these earlier projects created a strong link between the urban landscape and the houses.


Figure 130, Kingo house view over lake


Figure 131, Kristine park houses

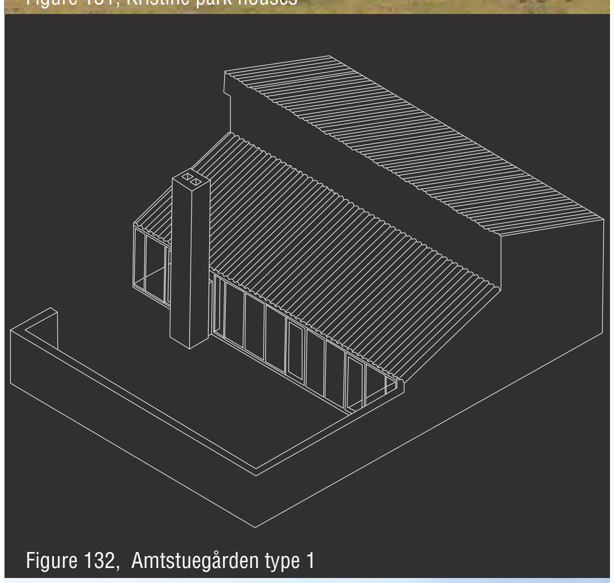


Figure 132, Amtstuegården type 1


Figure 133, Sjølundsparken view over the lake

CASE STUDIES

A case study of low and dense residential housing

The idea behind the low and dense residential housing was initiated in the late 1950s and through the 1960s by several prominent Danish architects. Each of the architects designed their proposal for a new interpretation of terraced houses; e.g. 'Kirstineparken' designed by Bo & Wohlert in 1965. These architectural projects became a great inspiration for subsequent low and dense residential housing projects.

In the 1930s, terraced houses were placed on a single straight line, and all the houses were uniform. In the early 1960s, architects started to play with a new interpretation of a terraced house, and the characteristic change was that of emphasizing each dwelling as unique, even though it remained in a line of buildings.

The unity between the houses emerged from the unified impression of being joined together in use of materials and construction. The architects used screen walls, which underlined the focus on individual and private spaces that were prior to the community and the whole. Prior to the low and dense housing movement, the terraced house type was built with a strong focus on the economy. Now the architects chose to focus on the surrounding landscape of the site, which had a strong influence on how the houses were placed and designed.

This project took its inspiration from some of the early low and dense projects, such as the Kingo houses designed by Jørn Utzon and a later project from the 1970s, the Sjølundsparken designed by Bente Aude and Bøje Lundgaard. There following four case studies, shown in figures 130-133, on low and dense residential housing projects have been used as inspiration and some will be referred to in the presentation [Ørum-Nielsen 1988].

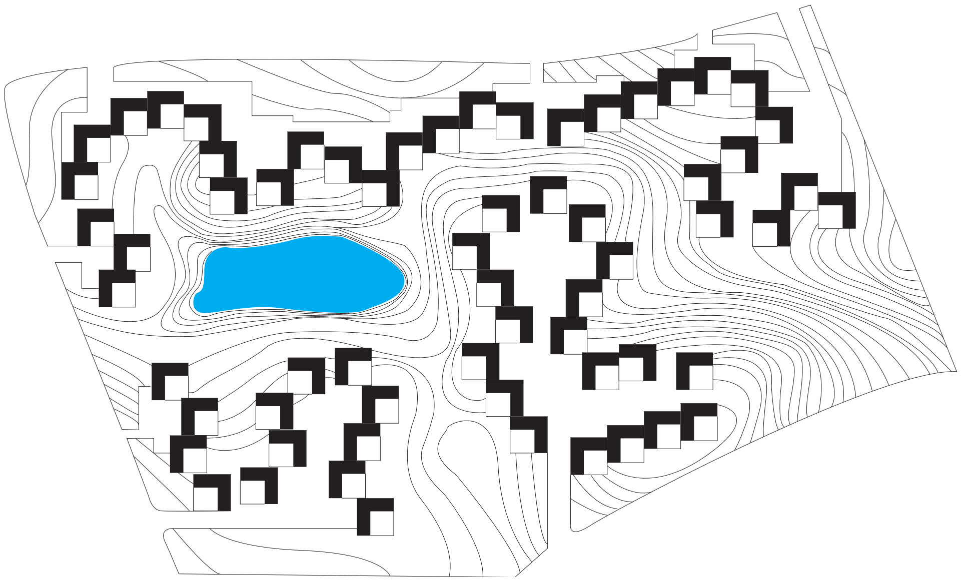


Figure 134, Kingo house urban plan

CASE STUDY 1

Kingo houses, Helsingør

Facts

- Place : Helsingør, Denmark
- Year : 1958-60
- Architect: Jørn Utzon
- Number of houses: 60 of 100 m2

The ‘Kingo houses’ were erected in 1958-1960 and are one of the first examples of Utzon’s additive architecture. The additive architecture is notable in how the uniformed designed houses have been joined together in different ways to follow the surrounding landscape so that each house is ensured a proper view of the surroundings.

The displacement of the houses creates the diversity and the signature shape of a snake twisting through the landscape,see figure 134. The coherent link between the houses is established by using a homogeneous choice of material, a yellow brick stone and the characteristic chimneys.

The brick walls surrounding each dwelling have two functions: protecting the privacy of the family and creating an open link to the surrounding community.

The project consists of 60 houses, all 100m2. The L-shaped houses are inspired by the Roman atrium dwellings. All the houses are designed on the same planning principle: a living room placed in the one rectangular section of the L-shape and bedrooms in the other rectangle. The kitchen and bathroom were placed as a link between the two rectangles. The floor plans can vary, as shown in figures 136-137.

Each house folds around a squared shaped atrium, into which the residents can enter directly from the living room. This project has since inspired several architects, and the inspiration is quite visible in the three case studies that follow [Kingohusene 2014].

Figure 135, Kingo house view over lake

Figure 136, Kingo house plan 1

Figure 137, Kingo house plan 2

Figure 138, Kristine park houses

Figure 140, Kirstine park ground floor plan

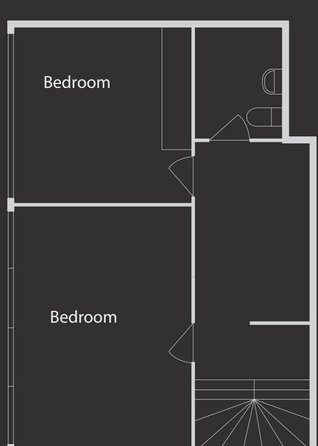


Figure 141, Kirstine park 1 floor plan

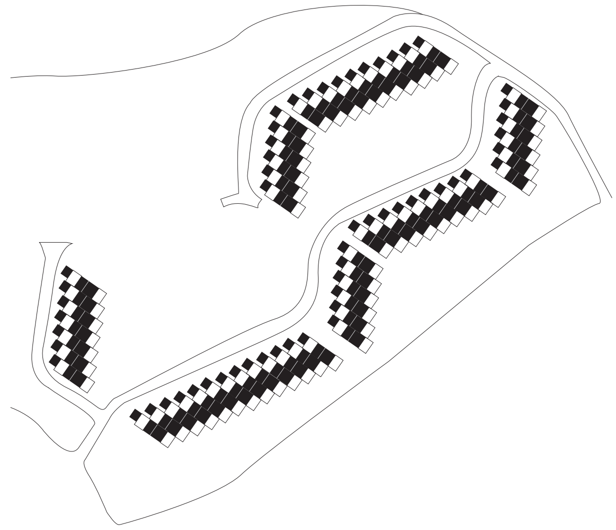


Figure 139, Kirstine park urban plan

CASE STUDY 2

Kirstineparken, Hørsholm

Facts

- Place : Hørsholm, Denmark
- Year : 1965-68
- Architect : Bo & Wohlert practice
- No. houses: 50 houses of 1½ floors, 3 housing types, all on 137m2 with basement

'Kirstineparken' was designed in 1962 by the architects Bo and Wohlert. The design was strongly inspired by the 'Kingo houses' project. Kirstineparken houses were constructed on a site in Hørsholm, north of Copenhagen, in close proximity to a large protected wilderness area and surrounded by traditional Danish single-family houses.

The urban landscape in the project has been created by dissolving the traditional straight line of houses, displacing them in a rhythmical pattern, illustrated in figure 138. The goal was to design single family houses in close proximity to each other while allowing the buildings to shape the green spaces.

The houses were connected by the long gables, and their individuality was expressed by using tall brick screen walls between the houses. The inspiration from the 'Kingo houses' was strongly represented in the screen walls, the displacement and the use of a homogenous building materials, which consisted of yellow bricks and red roof tiles.

The merging between a traditional terraced and single family house is clearly represented in this project. The houses have been placed in eight clusters,, each having 6-7 dwellings, and the dwellings were separated by pathways. Figure 132 shows how the architects designed the line of houses to open up and close in so as to create private spaces and link the site to the unspoiled nature area nearby.

Each house has a carport designed to shelter the entrance to the house from the common area. There are 50 houses, all with 1½ floors and on 137m2, figures 140-141 illustrates the plan layout. They all have the same façade expression but can vary in three different floor plans. All the houses have living rooms facing south-west. The living rooms are connected to a small garden and with a view to the common green areas [Kirstineparken - arkitektur 2016].

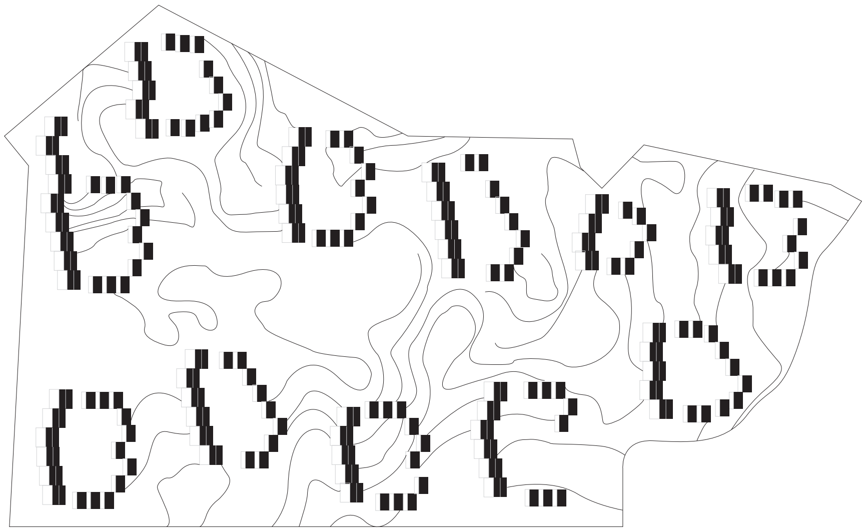


Figure 142, Amtstuegården urban plan

CASE STUDY 3

Amtstuegården, Hillerød

Facts

- Place : Hillerød Denmark
- Year : 1962, not built
- Architects : Inger and Johannes Exner
- No. houses: 172 houses, 2 types: 128 m2 and100 m2

In 1962, the two Danish architects Inger and Johannes Exner designed a proposal for a low and dense residential housing project. The project was commissioned by a wealthy property owner, named Anker Simonsen, who desired to build houses on a large orchard that he owned. The project was called 'Amtstuegården' and was developed in a teamwork consisting of the Exner couple, the landscape architect Sven Ingar Anderson and a young Jan Gehl.

The project resembles the 'Kingo houses', but the Exner couple was inspired by a little Italian village they had visited during a study trip. The village had been erected to follow the contour lines from the landscape. All the houses were connected together by the gables. In the centre of the village, all the villagers often encountered each other around a water post. The water post was placed so that it was almost impossible for the villagers not to pass by it on the way home. This created a natural social flow and gathering.

The inspiration from the village is visible in the planned urban layout, see figure142. The Exners designed 11 clusters, each of which resembled the Italian village. There were eight clusters with 15-16 houses, and three more with each 10, 14 and 20 houses. The formation of the clusters followed the landscape's uneven terrain, the result being that no single cluster was alike.

The clusters are thoughtfully designed, and two types of houses were used. The first type is a house on 128m2 distributed on two floors, facing south-west, with a one-sided high roof sloping toward the north-east and a short, one-sided low sloop toward the south-west. This type has a private garden, see figure 143. The second type is on 100m2 distributed on two floors in a single rectangle oblong shape, with a one-sided roof sloop toward south-west. This house type has no private garden but instead has a large terrace on the first floor. This type is designed to close off the cluster, as shown in figure 144. Unlike many other low and dense residential housing projects, the Exners decided to incorporate the carports as a significant element in the housing projects. All the houses should have had a carport connected to the common areas. The idea was to create a space where the car became a gathering point, like the water post in the Italian village. The project was never realized due to Anker Simonsen having fallen ill shortly after the design was completed [Jensen 2012].

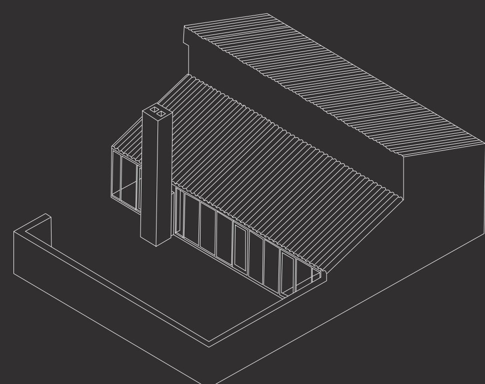


Figure 143, Amtstuegården type 1

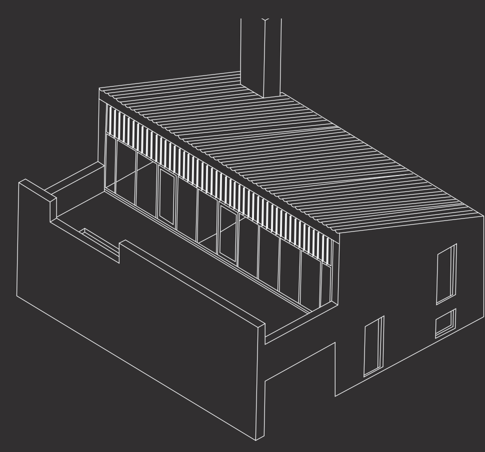


Figure 144, Amtstuegården type 2

Figure 145, Sjølundsparken urban plan

CASE STUDY 4

Sjølundsparken, Hellebæk

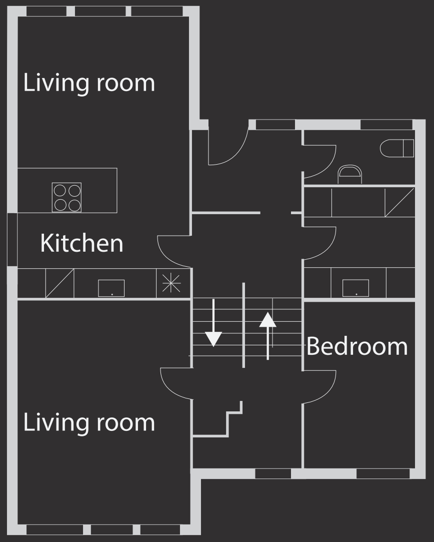


Figure 146, Sjølundsparken ground floor plan 166 m2

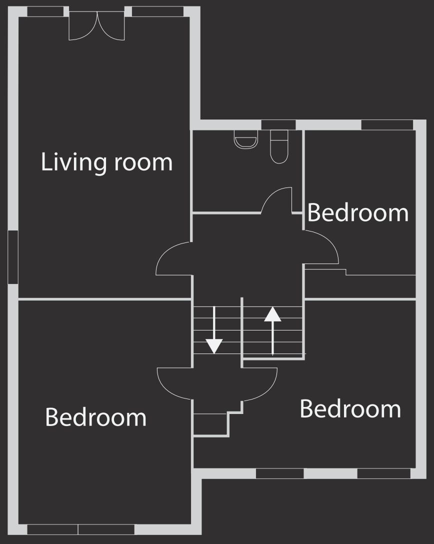


Figure 147, Sjølundsparken 1 floor plan 166 m2

Facts

- Place : Hellebæk, Denmark
- Year : 1978
- Architects : Bente Aude and Bøje Lundgaard
- No. houses: 74 houses, 17 types varying from 116 m2 to 166 m2

In 1978, two Danish architects, Bente Aude and Bøje Lundgaard, designed a classic example of the low and dense residential housing, the Sjølundsparken. Lundgaard was fascinated by new building techniques, energy+saving dwellings and low/dense residential housing.

Bente Aude dedicated her attention to interior design and sought to design the Sjølundsparken houses with consideration for the welfare of the residents and future prospects of the houses. They cooperated with the landscape architect Svend Kierkegaard.

The site is located in the village of Hellebæk, a few kilometres west of Helsingør and has an ocean view over the Øresund strait [Sjølundsparken historie 2016].

In the 1970s, the architectural and social examples for low/dense residential housing projects were greatly inspired by old domestic provincial villages. These villages represented a simple way of life, with a clear style of building techniques that evolved into a harmonious whole.

The villages are composed of houses that create long streets, market places and green urban spaces, see figure 145. Due to the houses having been constructed by different developers in different time periods, a harmonious diversity was created. In villages, this development occurs due to natural causes, while in newly erected housing projects, it is done for the sake of the effect [Ørum-Nielsen 1988].

This diversity is clearly represented in Sjølundsparken. There are 74 terraced

Figure 148, Sjølundsparken view over the lake

houses, composed of 17 different types. The houses are joined together by the gables in varying sizes of groups around a lake. They vary in size from 116m2 to166m2, with 16 different lot sizes. Figures 146-147 illustrates plan layout of a 166 m2 large house. The architects used the same building materials, roof pitch and mutual principal for plan and facades so as to create a correlation between the houses. The materials used are black painted horizontal wooden boards, light grey painted brick gables, yellow roofing slate and windows with a warm orange wooden frame [Sjølundsparken bebyggelse 2016].

All the houses are placed around a great lake, with wild nature and large old trees. The houses are placed relatively close together, which allows more of the surrounding nature to be preserved around the site, see figure 148.

The space between the houses creates private streets and small courtyards, which invite to social gathering, and create a place for the residents to meet and their children to play in a safe community. Short trees have been planted. The residents have placed benches with tables under the tree crowns, which are often used during the summer for social activities. Due to the courtyards being no longer than 30 metres and no wider than 20 metres, a pleasant atmosphere is created which invites people to meet and socialize.

The houses have been placed in groups that are divided by slender pathways, as shown in figure 139. These pathways allow for at least five different views from the courtyards.

The parking facilities have been placed on the outskirts of the cluster of residential housing. This is completely opposite the previously mentioned projects. Removing the cars from the houses allows for the creation of a more intimate and safe environment for the residents to interact.

Figure 149, Sjølundsparken, courtyard

Figure 150, Sjølundsparken, courtyard 2

Figure 151, Sjølundsparken, the houses

Figure 152. Sjølundsparken , the rhythm

APPENDIX A

Figure 153, Expan sound proof
concrete structural floor

EXPAN Lyddæk rumvægt 1750 kg/m³ - bæreevnetabel 220 og 240 mm

1. linie Max. regn. mæss. bæreevne i kN/m2 (excl. egenlast) ved jævnt fordelt last
2. linie Bæreevne i kN/m2 (excl. egenlast) ved langtidsnedbøjning < 1/300 af lysvidden
3. linie Max. karakt. bæreevne i kN/m² (excl. egenlast) ved jævnt fordelt last som bygningsdel klasse R 60 A1

Tværsnits-kapaciteter incl. egenlast: Vd, Md, Vk, Mk

Fri afstand mellem understøtningerne i mm (lysvidde) samt pilhøjde på støbeform i mm

Element type	Egen-last kN/m²	Vd max kN/m	Md max kNm/m	Vk R 60 A1 kN/m	Mk R 60 A1 kNm/m	Linie	2800 3,8	3000 4,3	3200 4,9	3400 5,6	3600 6,2	3800 6,9	4000 7,7	4200 8,4	4400 9,2	4600 10,1	4800 11,0	5000 11,9	5200 12,8	5400 13,8	5600 14,9	5800 15,9	6000 17,0	6200 18,2	6400 19,4	6600 20,6	6800 21,8	7000 23,1
220/31		68,99	34,70			1	29,87	25,60	22,09	19,17	16,72	14,63	12,85	11,31	9,98	8,81	7,78	6,87	6,07	5,35	4,70	4,12	3,60	3,12				
						2	27,98	22,90	18,90	15,71	13,13	11,01	9,25	7,78	6,53	5,47	4,56	3,77	3,09	2,49	1,96	1,50	1,08	0,71				
				45,50	27,50	3	22,85	19,47	16,69	14,37	12,43	10,78	9,36	8,14	7,09	6,16	5,35	4,63	3,99	3,42	2,91	2,45	2,03	1,66				
220/32		70,44	45,70			1	40,59	34,96	30,34	26,50	23,27	20,52	18,17	16,15	14,39	12,85	11,50	10,30	9,24	8,29	7,44	6,68	5,99	5,36	4,80	4,28		
						2	34,13	27,98	23,16	19,32	16,21	13,67	11,56	9,80	8,32	7,05	5,97	5,04	4,23	3,52	2,90	2,35	1,86	1,43	1,04	0,69		
				60,67	36,42	3	31,54	27,06	23,38	20,32	17,74	15,55	13,68	12,07	10,66	9,44	8,36	7,41	6,56	5,80	5,13	4,52	3,97	3,47	3,02	2,61		
220/33	3,95	72,72	64,00			1	46,81	43,50	40,59	38,02	34,17	30,32	27,03	24,20	21,73	19,58	17,68	16,01	14,52	13,19	12,00	10,93	9,97	9,09	8,30	7,58	6,91	6,31
						2	43,21	35,50	29,47	24,67	20,79	17,63	15,01	12,83	10,99	9,42	8,09	6,94	5,94	5,06	4,30	3,63	3,03	2,50	2,03	1,60	1,22	0,88
				60,67	54,17	3	38,40	35,64	33,21	31,07	28,31	25,06	22,27	19,87	17,79	15,96	14,36	12,94	11,68	10,56	9,55	8,65	7,83	7,09	6,42	5,80	5,24	4,73
220/34		74,80	78,51			1	48,27	44,86	41,87	39,23	36,87	34,76	32,85	30,58	27,55	24,91	22,59	20,53	18,71	17,08	15,62	14,31	13,12	12,05	11,08	10,19	9,38	8,63
						2	49,98	41,12	34,19	28,68	24,23	20,60	17,60	15,10	13,00	11,21	9,68	8,37	7,23	6,24	5,37	4,60	3,92	3,32	2,78	2,30	1,86	1,47
				75,83	67,08	3	48,99	45,53	42,50	39,82	36,00	31,98	28,53	25,55	22,97	20,71	18,72	16,97	15,41	14,02	12,77	11,65	10,64	9,72	8,89	8,13	7,44	6,80
220/35		76,89	92,42			1	49,73	46,22	43,15	40,43	38,01	35,84	33,88	32,11	30,49	29,02	27,29	24,87	22,72	20,81	19,09	17,54	16,15	14,89	13,74	12,69	11,74	10,86
						2	56,05	46,16	38,42	32,28	27,32	23,28	19,94	17,15	14,81	12,82	11,13	9,66	8,40	7,29	6,33	5,48	4,72	4,06	3,46	2,93	2,45	2,01
				91,08	79,58	3	59,63	55,48	51,84	48,62	43,45	38,67	34,58	31,05	27,99	25,31	22,95	20,87	19,02	17,37	15,89	14,56	13,36	12,27	11,28	10,38	9,56	8,81
240/32		75,80	50,50			1	44,91	38,70	33,59	29,35	25,77	22,74	20,15	17,91	15,96	14,26	12,77	11,45	10,27	9,23	8,29	7,44	6,68	5,99	5,37	4,79	4,27	3,79
						2	42,75	35,14	29,17	24,42	20,57	17,43	14,83	12,65	10,82	9,26	7,92	6,77	5,76	4,89	4,12	3,44	2,84	2,31	1,83	1,40	1,01	0,67
				60,67	40,08	3	34,77	29,83	25,78	22,41	19,57	17,17	15,11	13,33	11,78	10,44	9,25	8,20	7,27	6,44	5,69	5,02	4,42	3,87	3,37	2,92	2,50	2,12
240/33	4,30	78,05	70,91			1	50,19	46,63	43,51	40,75	37,93	33,67	30,03	26,89	24,15	21,77	19,67	17,81	16,16	14,69	13,38	12,19	11,12	10,15	9,27	8,47	7,74	7,07
						2	54,38	44,78	37,26	31,28	26,45	22,51	19,25	16,53	14,24	12,30	10,64	9,20	7,96	6,88	5,93	5,09	4,35	3,69	3,10	2,58	2,10	1,67
				60,67	59,83	3	38,05	35,29	32,86	30,72	28,81	27,09	24,67	22,01	19,71	17,70	15,92	14,36	12,97	11,73	10,62	9,62	8,71	7,90	7,15	6,48	5,86	5,29
240/34		80,11	87,15			1	51,62	47,98	44,77	41,94	39,42	37,16	35,12	33,27	30,67	27,74	25,16	22,88	20,85	19,04	17,42	15,97	14,65	13,46	12,38	11,39	10,49	9,67
						2	63,07	51,99	43,32	36,43	30,87	26,33	22,58	19,46	16,83	14,60	12,69	11,05	9,63	8,39	7,30	6,34	5,50	4,74	4,07	3,47	2,93	2,44
				75,83	74,17	3	48,64	45,18	42,15	39,47	37,08	34,94	31,61	28,32	25,46	22,96	20,77	18,83	17,10	15,57	14,19	12,95	11,83	10,82	9,90	9,06	8,29	7,59
240/35		82,17	102,79			1	53,06	49,32	46,03	43,13	40,54	38,22	36,13	34,23	32,51	30,93	29,48	27,75	25,36	23,23	21,32	19,60	18,05	16,65	15,37	14,21	13,15	12,17
						2	70,88	58,48	48,78	41,07	34,85	29,78	25,59	22,10	19,17	16,68	14,55	12,72	11,13	9,75	8,54	7,48	6,54	5,70	4,95	4,29	3,69	3,14
				91,08	88,17	3	59,28	55,13	51,49	48,27	45,40	42,83	38,38	34,48	31,08	28,11	25,50	23,19	21,14	19,32	17,68	16,20	14,87	13,67	12,58	11,58	10,67	9,83

APPENDIX B

Technical drawings

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