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Approaches to the design of sustainable housing with low CO_2 emission in Denmark

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ABSTRACT

Over the last year there has been a remarkable change in politicians' attitudes within Denmark and EU member states to the issue of climate change. This change in the political mindset is a result of the increasing frequency of high winds and flooding in Denmark and Europe, as well as in many other places around the world in recent years. This has resulted in an increasing challenge in terms of the planning, design and building of more sustainable buildings in order to reduce the use of energy for heating and cooling in new housing projects by bringing down the emission of CO_2 by reducing the amount of fossil fuel consumed by the built environment. This is crucial since carbon dioxide is one of the so-called greenhouse gases that is playing a major role in global warming. There is thus an increased focus on reducing the CO_2 level on a national and global scale. This article will look at the architectural and legislative changes in Denmark in relation to the increased political interest in the consequences of climate change. The article also discusses a survey of different types of approaches to the sustainable design of buildings and shows examples of new Danish housing projects that can minimise the use of energy for heating and cooling in the shape of detached houses, as well as a master thesis on high-rise houses.

1. Introduction

The starting point of this paper is the remarkable change in concern for the environment resulting from the changes in weather conditions and increasing gale activity and flooding over recent years in many cities in Denmark and Western Europe, as well as in many other parts of the world. This change in interest, or in focus, is being followed up by politicians in the EU, the European Parliament and the government in Denmark. The article will discuss some approaches where buildings can contribute to a reduction of CO_2 emissions instead of contributing to an increase of the CO_2 level. This change in attitude to climate problems has also been forced by Former Vice President of the United States Al Gore's visit to different countries in Europe during the winter of 2006/2007 and his concerns on global warming related to the increasing amount of CO_2 in the atmosphere as described in his book "An Inconvenient Truth" [1]. This change in interest or in focus is being followed up by politicians in the EU, the European Parliament and by the government in Denmark. In 2007 the EU Commission produced a Green Paper with options for the EU with regard to further action to cope with climate change. [2]

2. The influence of the legislative development of energy regulations on Danish architecture

Since 1961 Danish building codes have gone through several stages of specification of the demands for energy requirements in buildings. The legislative development can be divided into the following types of energy regulation [3]:

- Insulation of the building envelope
- Restriction of the window area
- Calculation of the energy requirement in relation to an energy frame

The most significant changes to the Danish building codes occurred in 1977, 1979, 1985, 1995 and 2006.

The 1979, 1995 and 2006 building codes introduced significant changes in the permitted insulation values (*U*-values) for the

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building envelope, while the 1977, 1985 and 2006 building codes have introduced different approaches to energy calculation and the window areas in buildings.

2.1. Architectural development

The legislative development with respect to energy has of course had an impact on the architectural expression of buildings in Denmark.

In the 1960s and early 70s the architectural consequences of the energy regulations were not significant. This was due to the fact that the regulation mainly focused on the introduction of 70–80 mm insulation in building constructions. The energy regulations of the 1960s and 70s were therefore primarily visible in the construction thickness of the building envelope. The 1977 building codes introduced a restriction on the window area to a maximum of 15% of the floor area in residential buildings. This resulted in a series of houses with poor daylight conditions, and large room depths or small windows. This restriction of the window area continued until 1985 where the possibility of calculating the energy requirement in relation to an energy frame for Danish buildings was introduced. The 1985 and 1995 energy calculations focused on the requirement for space heating. The change was welcomed by architects, who were happy with the possibility of increasing the window area beyond 15% of the heated floor area.

Unfortunately, this led to a series of highly glazed buildings which in many cases had problems with uncomfortably high indoor temperatures during hot summer periods.

In 2006 the energy frame was reduced significantly compared to the 1995 energy frames and two low-energy class energy frames were introduced. Furthermore, the way of calculating the energy requirements of buildings was changed to include the energy required for cooling, lighting and removing the build up of heat in buildings.

The new energy legislation does not forbid highly glazed buildings, but the reduction of the energy frame and the new way of calculating the energy requirement will probably render the approval of these buildings impossible.

The energy frames in the 2006 as well as in the new 2008 building codes for residential buildings are divided into two different levels of energy consumption: a low-energy class 1 energy frame of 35 kWh/m^2 + 1100/A (heated floor area) per year and a low-energy class 2 energy frame of 50 kWh/m^2 (kilo kilowatt hour per square metre) + 1600/A (heated floor area) per year (Fig. 1).

Additions can be made to the energy frame for buildings that have ventilation rates, lighting requirements or hot water consumption which exceed average values.

The new low-energy energy frames and the new way of calculating the energy requirement of buildings are expected to lead up to a 50% reduction in the energy consumption for space heating of new buildings.

Considerations are currently being made as to whether to introduce yet another low energy frame corresponding to the German Passive House Standard, which goes even further than low-energy class 1.

Building type	Energy frame (A: is the heated floor area)	Conditions
Residential	70kWh/m^2 + 2200 kWh/A	Energy consumption for space heating, basic ventilation (0.5h^{-1}), cooling and hot water
	Low-energy class 2: 50kWh/m^2 + 1600/A	
	Low-energy class 1: 35kWh/m^2 + 1100/A	

Fig. 1. Shows the current equations for the calculation of energy frames, which state the values that the annual energy consumption must not exceed.

3. Different approaches to sustainable architecture

Sustainable architecture is often associated with the Brundtland Report definition of sustainable development: "*sustainable development seeks to meet the needs and aspirations of the present without compromising the ability to meet those of the future*" [4].

Because of its broad definition, sustainability is often used as an umbrella term to cover the other terms found in the field. The broadness of the definition is, however, also the reason why the term is often criticised for being ambiguous [4,5]. A study of the architectural expression found within the field also shows that projects are rarely referred to as sustainable. Instead they are often referred to as environmental, ecological, low-energy, green or bioclimatic. These terms can be regarded as different approaches to sustainable architecture.

Generally all the approaches to sustainable architecture are concerned with one of two issues: approaches which "*embody the notion that the design of buildings should fundamentally take account of their relationship with and the impact on the natural environment*"; or approaches which are "*concerned with the concept of reducing reliance on fossil fuels to operate a building*" [6].

3.1. Design principles and motivations applied in the different approaches to sustainable architecture

From a methodological point of view, some of the publications that are available contain descriptions of design strategies, design principles and issues or concerns associated with the different approaches to sustainable architecture. Generally, these all emphasise the importance of the climatic and/or cultural context in which the project is placed, and approaches address many of the same design principles and issues or concerns, as seen in Figs. 2 and 3.

Figs. 2 and 3 illustrate the result of a study of the design principles presented in publications describing different approaches to sustainable architecture, and the main issues and concerns that motivate the studied approaches. The issues or concerns are assigned in accordance with the design principles applied by the different approaches, as well as in the definitions found for the term associated with the respective approaches. The left side of the illustrations shows a catalogue of the design principles found in publications [6–21]. The column in the middle shows the investigated approaches, and the column on the right side shows a categorisation of the main issues or concerns. The categorisation of issues and concerns was inspired by Hagan and Williamson et al. [5,6]. The dashed lines are used when the design principle is only suggested by some of the publications describing the respective approaches to sustainable architecture.

Most of the approaches discussed in this paper precede the Brundtland report. Exceptions are the sustainable approach, which is inspired by the Brundtland report, and the passive house idea, which was formulated in 1987 and 1988 by Professor Bo Adamson at Lund University (Sweden) and Director of the Passive House Institute in Darmstadt (Germany), Dr. Wolfgang Feist, respectively [22].

Despite the seemingly close correlation between the design principles and issues or concerns of the different approaches, there

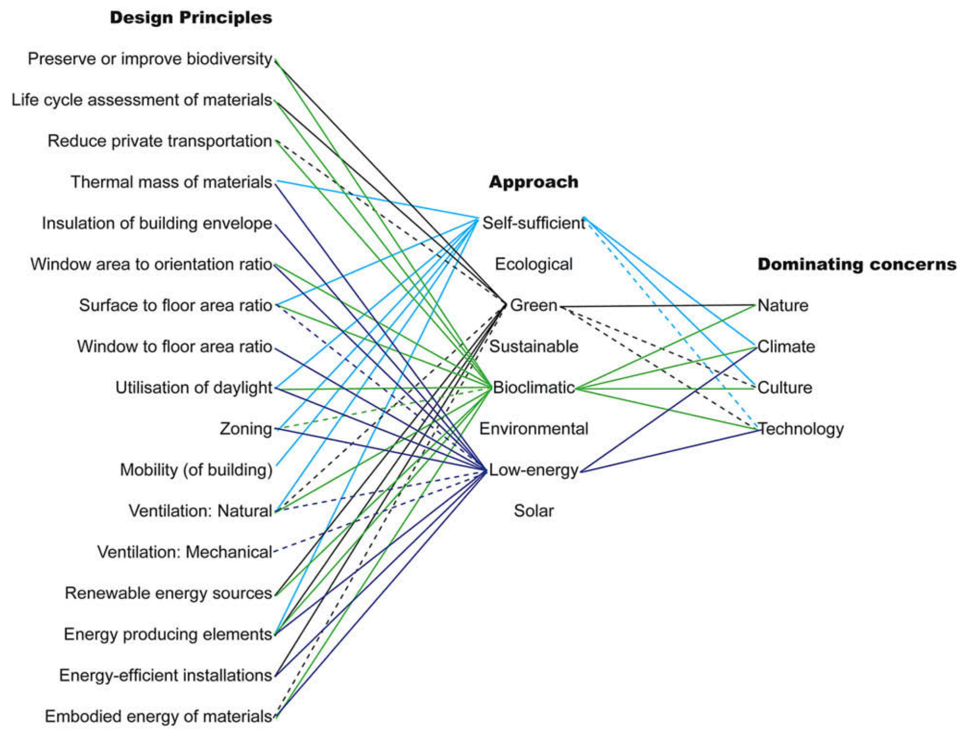

Fig. 2. Mapping of different approaches (self-sufficient, green, bioclimatic and low-energy) to sustainable architecture and their design principles and dominating concerns.

are large differences in the scale of focus which determines the strategy associated with the respective design principles in relation to e.g.:

- A global (climate and technology) vs. a local (nature and culture) scale of focus
- The scale of the design: urban development, site planning, building design and building components

There are also differences in the approaches to the main issues or concerns, where some approaches are concerned with the human impact on *both* nature and climate; other approaches are

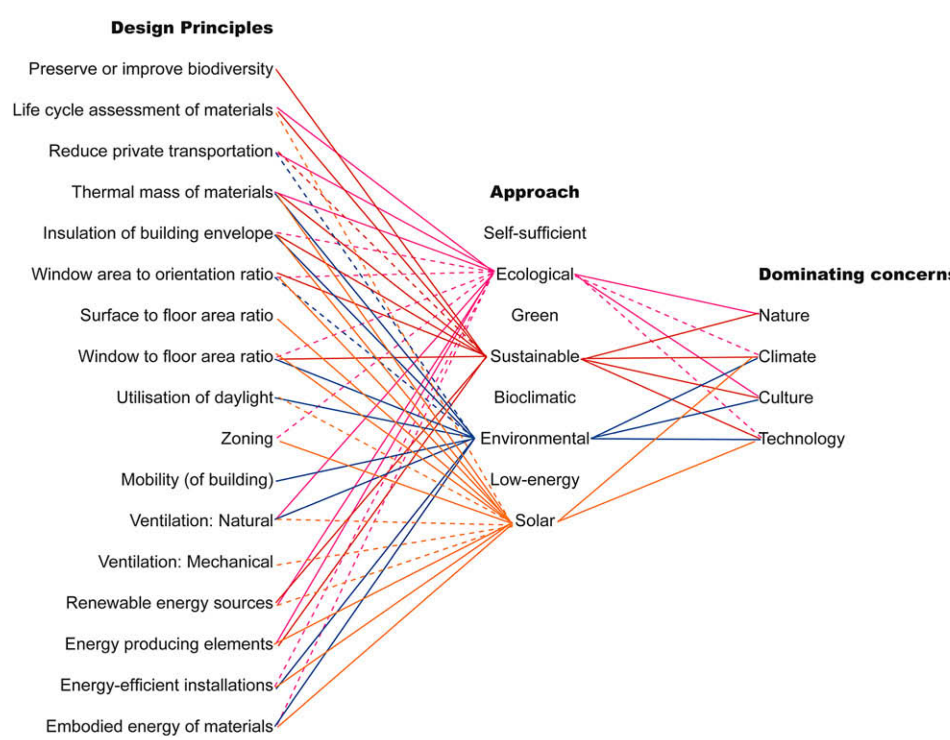

Fig. 3. Mapping of different approaches (ecological, sustainable, environmental and solar) to sustainable architecture and their design principles and dominating concerns.

mainly concerned with the climatic *or* the natural consequences associated with lifestyles. Furthermore, some approaches focus on the (socio)-cultural implications of lifestyles and/or on how technological development can solve the climatic and/or natural consequences of human behaviour.

Some of the dominant concerns applied in the approaches correspond to the application of specific design principles: Approaches concerned with nature prioritise biodiversity, life cycle profiles and toxicity of materials, reduction of transportation and renewable power sources over reducing the energy consumption in the building through the building shape; whilst approaches concerned with climate prioritise the reduction of energy loss through the building envelope (insulation, window area to orientation ratio, window to floor area ratio, surface to floor area ratio, zoning, thermal mass, mechanical ventilation) and reduction of electrical energy (utilisation of daylight, natural ventilation and energy-efficient appliances) over life cycle profile and human toxicity of materials, biodiversity and reduction of transportation.

This means that a design project will reflect the motivation of the project and the concerns taken in the project in the prioritisation of the applied design principles.

3.2. General principles and considerations associated with building in a temperate climate

Seasonal temperature variations require specific (environmental) approaches to building design, because the buildings have to be adaptable to different situations. It is thus important to register the seasonal climatic conditions in the early stages of the design process and incorporate these into the design brief.

Another important issue that the design brief ought to address is the user profile (i.e. the comfort requirements for temperature, daylight, acoustics and ventilation, as well as electrical appliances inside the building and work patterns of the user, etc.). The user profile and the climatic context influence the success and selection of design strategies for the applied design principles.

Once the climatic conditions are established, design strategies for how to ventilate the building, and achieve and avoid external heat gains, can be developed.

Design principles that are generally associated with the issue of achieving and avoiding external heat gains in temperate climates are

- Window areas and orientation (heat gain from the sun)
- Seasonal shade (heat gain from the sun)
- Insulation of the building envelope (temperature differences between indoor and outdoor temperatures)
- Minimising/avoiding thermal bridges (temperature differences)
- Surface to floor area ratio of the building shape (Surface area exposed to temperature differences)
- Air tightness of the building envelope (control of the air flow)
- Ventilation strategy (natural, mechanical, thermal mass activation)
- Zoning
- Selection of an energy-efficient ventilation strategy in relation to all seasons

The strategies applied in relation to these principles are determined by the seasonal variations of external air temperatures, wind speeds and directions, solar angles and azimuths, and of course the type of building and its architectural concept.

Design principles relating to the reduction of the electrical energy consumption of the building are:

- Utilisation of daylight
- Selection of an energy-efficient ventilation strategy in relation to all seasons
- Energy-efficient appliances
- Energy-producing elements outside the building or integrated into the building envelope

Other issues of interest can be included in relation to the profile of the building. For instance, a green project might also choose to include the following design parameters:

- Biodiversity (vegetation and wildlife)
- Life cycle assessments for the materials applied in the building
- Reduced private transportation (high urban density)

4. Examples of Danish projects under realisation

The Danish contribution to the reduction of environmental impact in the built environment has been implicit due to the legislative development described in the preceding paragraph. The main contribution that identifies Denmark as one of the leading countries in this area is the efforts made in the development of renewable energy sources and environmental planning during the 1980s and 90s. The primary Danish contribution has so far been the development of wind power, environmental planning and other environmental themes, such as water and nature conservation.

Despite the fact that Denmark has a reputation for being one of the leading nations when it comes to environmental issues, planning and management, *the fact is* that in the field of housing only a few building projects actually address the issue of climate and human impact on nature.

The recent increase in political and public awareness due to the increased visibility of climate change has, however, had a positive effect on the demand for sustainable residential housing. This has led to an increase in the number of sustainable projects under development addressing the issue of CO_2 reduction and healthy buildings. These projects also give examples of future detached single-family houses with low-energy class 1 and 2 buildings (35/50 kWh/m^2 + 1100/1600/A (heated floor area) per year).

The project described in the following is one of the few recently realised Danish residential projects addressing the issue of CO_2 reduction and healthy buildings. In 2006 the competition concerning future detached single-family houses in Herfølge ended. 86 competition contributions were received [23]. The projects were advertised and sold, and the construction of a number of the projects has begun.

The initial aims for the competition contributions were that:

- The houses should be energy-efficient (minimum low-energy class 2) and friendly to the environment
- The houses should promote healthy ways of living
- The houses should be affordable for families with an average income.

Fig. 4 shows an example of submitted projects from the project website. The house is designed by Arkitekterne Køge A/S [23]. The energy consumption meets the low-energy class 2 requirements and the reduced CO_2 emission is 29% lower than that of an average house. The primary energy source in this case is gas supplemented by solar panels for water heating, and the ventilation system is mechanical. The price was approx. 55,000 Euro, which is at the high end of the price range set for the constructed houses.

The competition resulted in both low-energy class 1 and class 2 buildings. The Herfølge project is an example of a sustainable

Fig. 4. A single-family house designed by the Architect studio Arkitekterne Køge A/S [23].

development of an urban area induced through urban planning and public funding supplemented with a design competition.

Since the Herfølge project, more competitions have been realised, e.g. Komforthusene ['Comforthouse project'] initiated by Saint-Gobain Isover Denmark, Zeta Invest A/S, Middelfart Sparekasse and 10 building consortiums which have each developed their type of new Danish passive house [24].

The purpose of the Comfort house project is to disseminate the knowledge of houses with passive heating, thus setting the agenda for future building projects and the political energy debate. The project involves a lot of partners, which means that the project also acts as a learning experience of how to deal with projects with multiple partners. The buildings will be completed and put up for sale in the autumn of 2008.

5. Example of a student project for environmental housing on the former goods railway area in Aalborg

In 1997 a new engineering degree was established at Aalborg University (Denmark). The course addresses the intermediate space between the architectural and building engineering degrees, as well as the professional gap present in the traditional approaches to architectural design in Denmark. The aim of the course is to bridge the professional gap between the architecture and engineering professions.

At the specialisation stage in the course, the Integrated Design Process (IDP) was used, which suggests a holistic approach to environmental building design [7,8]. The description suggests a methodical approach where the starting point is the architectural design process in which parameters from engineering are integrated from the beginning of the process into a hybrid design approach aimed at integrated design. This approach is not yet common in mainstream architectural and engineering practices in Denmark.

The project presented here exemplifies how future housing can help us to take care of the environment in a sustainable way. The IDP is applied for the design of this project, which is a master thesis from the Department of Architecture & Design at Aalborg University (Denmark).

The housing proposal suggests a sustainable building design with very low energy consumption and a comfortable indoor climate [25]. At the same time, the buildings contain high architectural qualities in terms of expression, functionality and spatial expression. The building satisfies the energy frame for low energy class 1, which is the strictest energy class in Denmark at the time of completion of the design (see Fig. 1).

The City of Aalborg has a number of wishes for the future development of the former goods railway area. One of the main guidelines for the area has been to create a green connection to the existing recreational area south of the city. Another guideline is to make a more open structure than the traditional way of building in the city centre (Fig. 5). An open structure (as displayed in Fig. 6) allows a flow of pedestrians into the area, thus creating a connection between the city centre and a number of recreational areas south of the city centre.

The simple building volumes emphasise the green element and vice versa. They give a strong expression to the area along with the amorphous and honest concrete paths. Each building contains 5 apartments, with car and bicycle parking, waste disposal, ventilation unit and storage located on the ground floor. The location of these secondary functions on the ground floor was chosen as a buffer to avoid problems with any residue from contaminated soil. The apartments consist of three types of apartments: One penthouse on the top floor and two types of apartments underneath (see Fig. 7 for the building and apartment concept).

The facades are lightweight and only support their own weight. The deadweight is transferred to the building's main structures that consist of plate elements, columns and cores. This principle is an economically sustainable solution, but most of all it allows one to increase the thickness of the insulation in order to get a better *U*-value without resulting in walls that are too deep.

Fig. 5. Pedestrian flows into the area from the historic city centre to the recreational areas.

Fig. 6. The site plan.

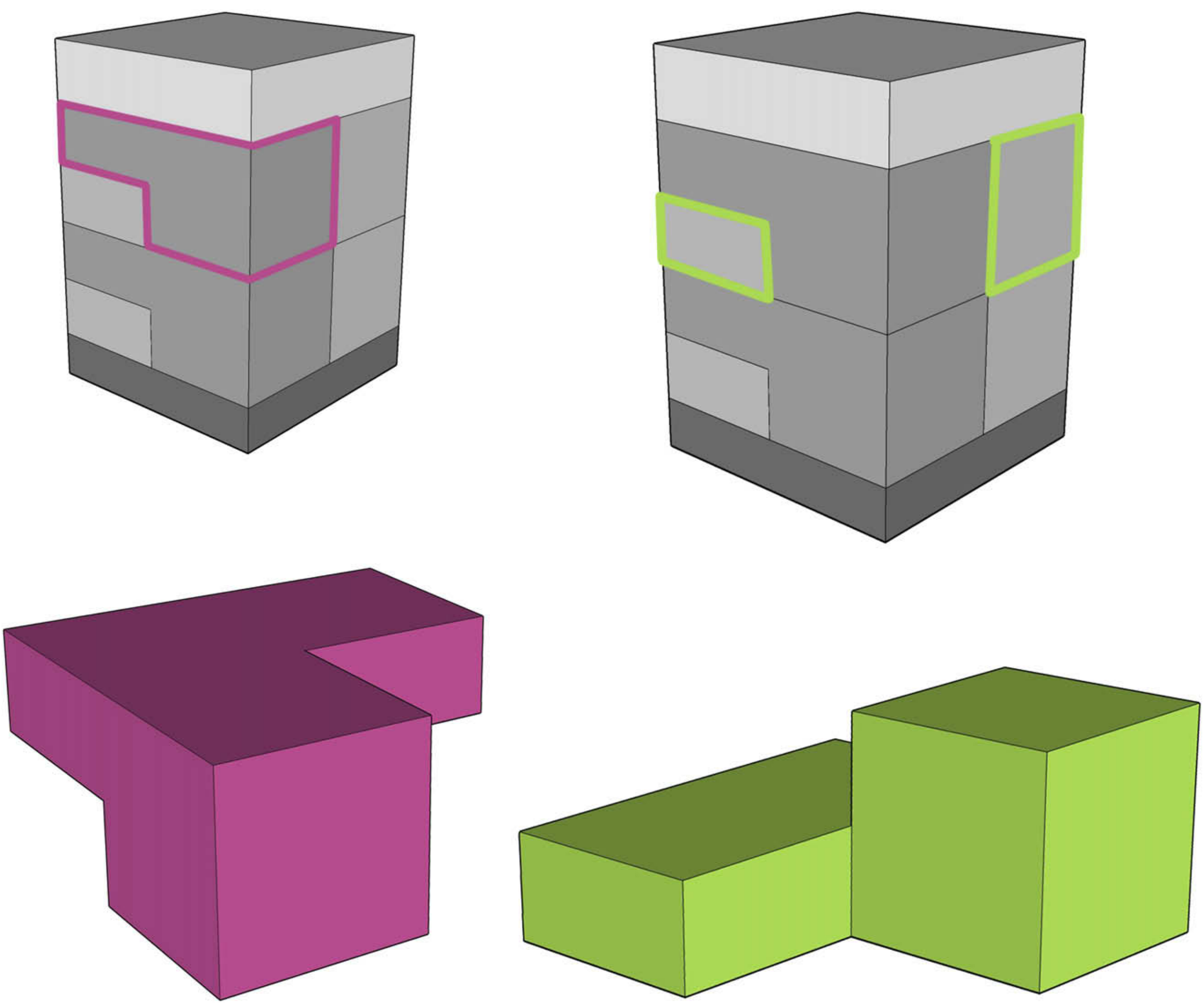

Fig. 7. The building and the apartment concept.

Fig. 8. Rendering of the facades.

The facades of the buildings are plastered in a dark grey colour, which makes the buildings appear dark and solid in contrast to the rough and unrefined atmosphere in the railway area (Fig. 8).

The balconies are made by cutting out volumes. This provides not only a private balcony, but also functions as an overhang for the windows underneath. The balconies therefore help protect against overheating inside the apartments during the summer. The walls and ceiling on the balcony are painted white and the floors are kept in light wood. This reflects the light into the room and gives better daylight conditions inside the apartment.

The facades have different levels of openness. The warm yellow light and the passive solar heat penetrate the windows of the open south-facing facade. This is especially important during the winter season. The other facades are more closed to prevent both overheating in summer and reduce the heat loss through the facade in winter. Architecturally, the closed facades emphasise the expression of the volume and clarify the concept.

Dynamic solar shading is integrated into the window design of the south-facing facade. This protects against overheating and gives a graphic and dynamic expression to the facade. The changing positions of the shading enable this graphic and dynamic expression, which means that the expression of the south facade changes as a function of the interior and exterior conditions.

Different principles are used to define spaces in all apartment types. These create some interesting spatial effects that have a high degree of functionality and stimulate the senses (see Fig. 9).

Simple elements, such as the core containing the bathroom and the wall by the balcony, define spaces in the apartments. This enables an open plan whilst indicating the functional zoning of the apartments. Minor spaces can be created via sliding doors. At the same time, the core elements also have a structural and thermal function. Heat can be accumulated in the concrete, thereby minimizing the temperature variations during the course of the day. The materials of the core elements are raw and untreated in contrast to the rest of the light-coloured and soft interior (Fig. 10). This contrast is underlined when the sunlight hits the element during the day and causes an interplay of light and shadow in the texture and colour of the element.

Another architectural approach applied in the apartments is that of double-height rooms. These rooms define spaces and functions in the apartment while creating light and spacious rooms. The open plan is preserved and contact between the rooms and functions is preserved.

As mentioned above, energy consumption is very low and meets the energy requirement for low-energy class 1 in Denmark (35 kWh/m^2 + 1100/A (heated floor area) per year), which is the strictest requirement at present. The extra insulation in the walls, the almost airtight construction, passive heat from the sun, the ventilation system with heat recovery, etc., mean that the building needs very little heating in winter. The low energy requirement can be supplied by the ventilation system, and the cost of a traditional heating system is thus saved.

The project takes a neo-modernistic approach to architecture and at the same time it uses a typical Danish minimalist architectural language. The project shows that it is possible to create good architecture in low-energy buildings in which CO_2 emission is

Fig. 9. Plan, level 1 (left) and level 2 (right).

Fig. 10. Living room (left) and kitchen (right).

minimised compared to conventional residential buildings. Furthermore, the project illustrates that it is possible to design buildings with architectural qualities where the passive and technical approaches are well integrated into the function and expression of the building.

It is, however, very important to remember that the application of the generally applied design principles does not result in the architectural design of the building. Design principles can only be used as guidelines in the integrated design process and must be combined with other tools, as well as the basic architectural concept of the building.

Architectural qualities need to be considered in relation to the design principles. Examples of considerations related to the architectural qualities of buildings are the expression, functionality, space design, views, lighting qualities, etc. All these aspects must flow together in a synthesis and inspire each other in the integrated design process in order to make good architecture with a combination of good architectural and technical qualities.

6. Conclusion

Based on the low-energy housing projects in Denmark, it is the conclusion of this article that technologies for renewable energy sources are only applied in exemplary housing projects in Denmark. This is mainly because renewable energy sources are not affordable in average housing because of the payback time of, for example, PVs and solar panels.

This means that renewable energy sources are usually not integrated into housing projects in Denmark. The new way of calculating the energy requirement of buildings has, however, increased the awareness of PVs and solar panels in the minds of building designers.

Danish architects therefore try to reduce the environmental impact of their designs through the application of passive design strategies and hybrid ventilation systems with heat recovery, instead of introducing renewable energy sources into their designs. In rare cases (like some of the projects described here) the passive strategies are supplemented with active measures in the form of wood chip ovens, PVs and solar panels.

When it comes to the utilisation of renewable energy sources in Denmark, there is a clear tendency for district CHP systems to be supplemented with renewable energy sources, e.g. in the form of windmill parks in rural or coastal areas. The energy source of some of the CHP plants has also changed from coal to straw, which results in a CO_2-neutral plant. The conversion of fuel types is attractive in Denmark because the Danish distribution systems are such an integrated part of urban planning.

An issue that needs to be addressed in the near future is what consequences the new energy requirements will have on architectural expression and building shape. The traditional way of building Danish residential buildings uses brick. After two years with the new building codes there is a tendency to abandon this previously preferred material as a means of achieving the low *U*-values required in the new building codes, because of the resultant thickness of the walls. This means that in future the expression of Danish buildings will change from brick to materials such as wood and plastered plates.

Another issue is whether people actually like living in these houses and how the users will control the indoor climate and whether the construction principles and air tightness of these constructions will cause condensation in the construction over time or within the building. This is a relevant concern with regard to the Passive House Concept because of the more humid climatic conditions present in Denmark compared to Sweden or Germany, from where the Passive House Concept originates.

Furthermore, there is a need to revise the way future urban plans and local plans are drawn up in relation to enabling sustainable housing. A revision must be made with respect to how to parcel out future housing areas in order to avoid contextual shade from the surroundings onto the building and in order to enable full utilisation of the passive solar energy. The contextual shade is an issue because the solar angle in Denmark is very low during the heating season (13° on December 22) when the passive solar heat gain from solar radiation is most desirable in Danish buildings.

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