New building principles in consequence of legislative demands for reduced energy consumption in Danish housing

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ABSTRACT: The increasing restrictions in coming building codes regarding energy consumption in housing generate a need to rethink the building design as well as the building process. This paper discusses the need to change/challenge the way structures are conceived in order to accommodate new legislative demands regarding energy consumption. More often than not sustainable aspects like the need for reduced energy consumption are implemented late in the design process. This paper investigates the affect of incorporating aspects like solar heat gain and energy consumption in the initial concept. With the right approach and tools, integrating sustainable thinking could/should produce new architectural layouts as well as new ways of designing houses. The emphasis of this paper is on the latter and will consider the implications that the challenging new demands have on contemporary architecture, exemplified with a case study. The case study evaluates different types of design principles of a typical Danish house, especially with respect to choices of materials etc. As the conclusion of this paper will show, unconventional thinking can negate this effect and even bring about new ways of working with materials and design as such.

Keywords: energy consumption, building codes, materials.

1. INTRODUCTION

With new restrictions concerning the allowable energy consumption of Danish dwellings, Denmark places itself in the forefront with some of the harshest legislative demands in Europe when it comes to energy consumption. Among the different approaches to accommodate the new demands, this paper focuses on the contextual and the technological methodology. Does the way a traditional Danish building is conceived have to be changed fundamentally or is it adequate to increase the amount of insulation used? This paper describes and evaluates the effects of implementing the new demands into a traditional Danish dwelling, in terms of building components and energy consumption.

To evaluate the impact of the new regulations a dwelling designed according to the old Danish energy requirements is modified through different steps to comply with the new the demands. This will describe the effect of changing the area and orientation of the windows, changing the amount of insulation and taking technological steps to further reduce the energy consumption. However the analysis presented in this article is only partial. A full analysis would have to consider the effects of changing the geometry of the rooms and the design, the effects of avoiding thermal bridges, implementation of solar heating panels and various heat pumps to mention some. [1] [6]

2. THE NEW ENERGY DEMANDS

2.1 Short introduction to the new demands

This section includes a short introduction to the increased focus on energy efficiency and indoor climate presented in the new Danish building codes [1].

The changes to the prior building codes are due to the EU directive about: "Energy efficiency in buildings" which requires that all buildings over 50 m^2 are to be provided with an energy declaration [2].

In order to ensure a decrease in energy consumption in future building projects several new measures have been made. Whereas the former building codes primarily focused on heating, insulation and amount of windows allowed the new regulations focus on primary energy consumption including energy use for hot water, mechanical ventilation and lighting. Also accommodated is the use of cooling, new means of heating (e.g. earth heating) and energy saving or the use of measures like heat pumps, heat recovery and solar panels. Furthermore an acceptable indoor climate is an integrated part of the energy balance. If the building becomes overheated the surplus of heat is considered disposed of by means of mechanical cooling which in turn will result in increased energy consumption. The use of electrical power is differentiated from central heating by a factor 2,5.

Additionally the association between windows and walls are of a more complex nature. The new building codes implement a threshold for heat loss of 6 W/m^2

for a building below 3 floors wall, floor and roof, window openings excluded. This demand is combined with the energy constraints which are divided into three classes [1]: The basic energy frame, Low energy class 2, Low energy class 1 (Table 1). It is only the requirement of the basic energy frame which is compulsory.

Table 1: The allowable energy consumption for a single family dwelling in order to comply with the different classes. *A* is heated floor area. Additional energy consumption for ventilation purposes is allowed under certain conditions

Energy Class	Amount
Basic energy frame	70 kWh/m^2+2000kWh/*A*
Low energy class 2	50 kWh/m^2+1600kWh/*A*
Low energy class 1	35 kWh/m^2+1100kWh/*A*

3. THE CASE

3.1 Introduction

The case study is based on a traditional designed Danish dwelling of 130 m^2 with a layout that provides ample lighting conditions and contact to the outside in all rooms. Consequently for the dwelling of 130 m^2 discussed in the following case study the energy frame and low energy classes are as follows;

Basic energy frame: 85,4 kWh/m^2
Low energy class 2: 62,3 kWh/m^2
Low energy class 1: 43,4 kWh/m^2

The dwelling is designed to meet the requirements of a family of three to four, but it is however not designed with the new building code in mind [Figure 1]. The case will explore three different approaches to make the dwelling comply with the new regulations. The calculations exclude energy use for lighting and pumps for hot water.

In addition to the demand a computer program (Be06) has been developed which enables you to estimate the energy use of a given building. The figures stated in this paper all derives from this program.

3.2 The contextual approach

The contextual approach takes the surroundings into account by adapting the characteristics of the location into the layout of the building, for instance by analyzing the site and climatic conditions in order to organize the building to utilize the resources in a given situation the best way, i.e. optimization towards solar heat gain in the winter time for a building situated in the northern hemisphere. [3] [4]

3.3 The technological approach

The technological approach focuses on implementing technical equipment to enhance the capabilities of a dwelling or a building, i.e. utilizing solar heating or mechanical ventilation with heat recovery. [3] [4]

3.4 The material based approach

By focusing on using the best suited materials to absorb and emit heat you can prevent large variation between day and night temperatures. The choice of material combined with making use of a suitable amount of insulation, can produce leaner yet better insulated walls than by just increasing the insulation in the traditional brick wall. Furthermore in choosing the right building principles thermal bridges can be avoided while constructing airtight solutions. [3] [4]

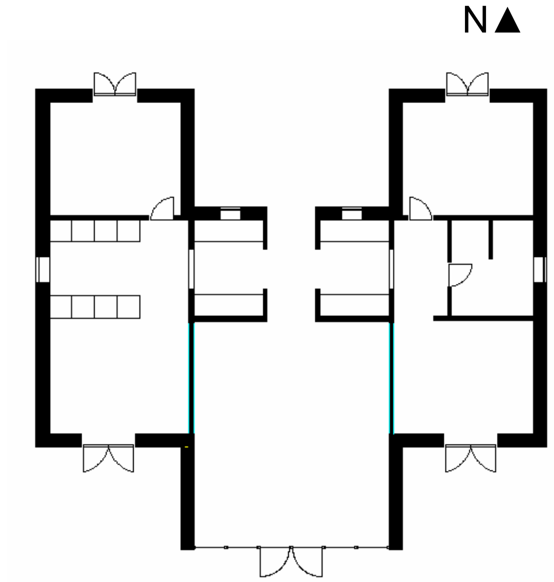

Figure 1: Floor plan of the analyzed dwelling. Not to scale

Table 2: *U*-values of the original layout based on new Danish codes [1]

Insulation	wall	floor	roof	window
U-value (W/m^{2}K)	0,24	0,13	0,13	1,40
Sand (mm) 1,20 W/m K		100		
Gypsum (mm) 0,20 W/m K			22	
Concrete (mm) 1,80 W/m K	130	100		
Insulation (mm) 0,039 W/m K	150	275	220	
Concrete (mm) 1,80 W/m K	65			

4. THE CONTEXTUAL APPROACH

4.1 managing the build environment

An appropriate arrangement of a building according to the climatic conditions is crucial in order to utilize or shelter from the climate. The first part of the case study considers revising the building according to the given external loads. Through this first part of the case study the *U*-values and internal heat load remain fixed.

4.2 The original layout of the building

The windows of the original layout are primarily facing north and south with some minor openings in the eastern and western façade (Table 3). Organizing the windows in this manner, using the minimum amount of insulation in order to comply with the 6 W/m^2 rule and ventilation without heat recovery, will result in a building using 86,2 kWh/m^2 divided into the categories depicted in Table 4. There are no problems regarding overheating, according to the calculation software based on monthly average values. This would have influenced the energy use in a negative way as overheating is calculated is disposed of by mechanical cooling. However this layout does not comply with the basic energy frame mainly due to the large amount of windows facing north.

Table 3: orientation and areas of windows and wall of the original layout.

orientation	N	S	E	W
Window area (m^2)	9	18	1,5	1,5
Wall area (m^2)	37	27	47,5	47,5

Table 4: the energy consumption of the original dwelling.

Energy consumption	kWh/m^2
Heating	85,6
Electrical power consumption	0,2*2,5
Overheating (mechanical cooling)	0
Total	86,2

Thus the original layout does not comply with the maximum energy requirement though it comes close, which primarily is due to the modifications already done before the optimization e.g. more insulation in the floor and roof than normally.

4.3 Reorganizing the orientation of windows

By reorganizing but maintaining the area of the windows, different situations will emerge. The obvious first step when building in the northern hemisphere is to reduce the windows facing north to an absolute minimum. In the following section three different situations are examined.

4.3.1 All windows facing south

Organizing all the windows towards south would of course result in some rather dark areas in the northern part of the dwelling. However this orientation should result in an increased solar heat gain combined with a decreased heat loss toward north. The results of the reorganization are illustrated in Table 5 and Table 6. As shown in Table 6 the reorganization of the windows has resulted in a significant decrease in energy use to heating. However with the increased amount of windows facing south problems with overheating in the summer period begin to occur.

Table 5: orientation and areas of windows and wall of the layout with a southern orientation of windows.

orientation	N	S	E	W
Window area (m^2)	0	30	0	0
Wall area (m^2)	45	15	49	49

Table 6: the energy consumption of the dwelling with all windows facing south.

Energy consumption	kWh/m^2
Heating	75,9
Electrical power consumption	0,2*2,5
Overheating (mechanical cooling)	3,7
Total	80,2

4.3.2 Windows facing east and west.

By rearranging the windows towards east and west, the building should be able to maximize solar heat gain in the morning and afternoon (Table 7). The problem with overheating from the former case is certainly not solved (Table 8). The heat consumption also increases due to the decrease in solar heat gain from the absence of windows facing south. The building no longer complies with the energy frame.

Table 7: with windows facing east and west the building no longer complies with the energy frame especially due to a decrease in solar heat gain and the consequently increased heating consumption.

orientation	north	south	east	west
Window area (m^2)	0	0	15	15
Wall area (m^2)	45	45	34	34

Table 8: the energy consumption of the dwelling with no windows facing south or north.

Energy consumption	kWh/m^2
Heating	93,0
Electrical power consumption	0,2*2,5
Overheating (mechanical cooling)	4,2
Total	97,7

4.3.3 The optimized solution

Organizing the windows primarily towards south and partly towards east and west, the solar heat gain towards south can be augmented without neglecting lighting condition in the rooms facing north. Overheating still occur in this scenario but to a lesser extent than with all the windows facing south.

Table 9: windows to the north rearranged to eastern and western façade.

orientation	north	south	east	west
Window area (m^2)	0	24	3	3
Wall area (m^2)	45	21	46	46

Table 10: the energy consumption of the dwelling with no windows facing north.

Energy consumption	kWh/m^2
Heating	80,1
Electrical power consumption	0,2*2,5
Overheating (mechanical cooling)	2,1
Total	82,8

Reorganization of the original layout of the building results in new configurations with different possibilities and complexities which have to be considered. Only one of the modified layouts results in a reduction in heating consumption. However problems with overheating emerge. This solution will still have a problem regarding overheating, a problem which cannot be solved by means of optimization in relation to orientation alone. The next step is to optimize the overhang over the windows or implement solar shading in order to deal with the overheating which primarily occurs in the summer period.

4.4 Overhang and overheating

Through modification of the layout illustrated in 4.3.3 regarding overhang over the windows, the solar heat gain in the most intensive hours of the day can be controlled and reduced (Figure 2), thus decreasing or eliminating the problem of overheating. The modified solution satisfies the need for natural lighting and contact to the surroundings in every room of the dwelling. At the same time the overall energy use is reduced from 86,2 kWh/m^2 in the original layout to 80,7 kWh/m^2 in the modified layout (Table 11)

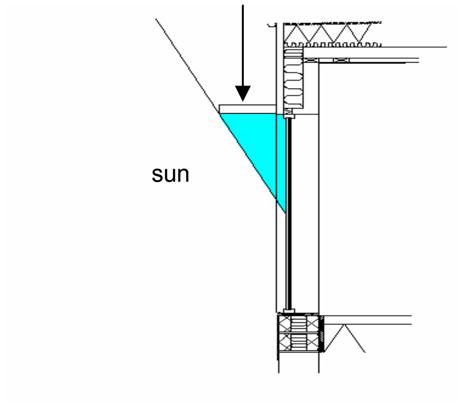

Figure 2: overhang of 200 mm over windows facing south. Not to scale

Table 11: the energy consumption of the dwelling with no windows facing north. With overhang of 200 mm over windows to the south.

Energy consumption	kWh/m^2
Heating	80,2
Electrical power consumption	0,2*2,5
Overheating (mechanical cooling)	0
Total	80,7

5. THE TECHNOLOGICAL APPROACH

5.1 Optimization through a technological approach

In order to further minimize the amount of energy used, another step is to implement technical solutions which will reuse the energy already in the building. By implementing mechanical ventilation with heat recovery with a heat exchange efficiency of 80 percent the modified building from 4.4 will have an energy consumption of 59 kWh/ m^2 (Table 12). This only represents a small segment of the possible technological steps one could take in order to improve the capabilities of a dwelling. The purpose of this paragraph is to illustrate some of the implications of implementing technological means in a dwelling.

Table 12: the energy consumption of the dwelling with no windows facing north. With overhang of 200 mm over windows facing south and mechanical ventilation with heat recovery.

Energy consumption	kWh/m^2
Heating	50,9
Electrical power consumption	3,2*2,5
Overheating (mechanical cooling)	0
Total	59,0

Consequently the building is upgraded to fulfil the requirement for energy class 2. The decrease in demanded energy may also be used to modify the layout to comply with any aesthetic or functional needs that may have been neglected in the first optimization process or to improve the indoor climate. That is if windows to the north is essential to the layout of the building, the desired wall thickness is 300 mm instead of the 350 mm or if overhang over the windows is undesirable. By implementing heat recovery in the design, the building would still fulfil the energy frame even though the windows removed from the original layout were reimplemented.

5.1.1 Using the technological approach to change the original layout

By employing heat recovery the building could actually comply with the energy frame even if the total area of windows is doubled (Table 13). The added windows have a primarily southern orientation. To reduce the substantial problem of overheating an overhang of 650 mm is positioned over all of the windows facing south. This amount of overhang is the minimum in order to be capable of meeting the terms of the energy frame. However there still remain problems of overheating (Table 14), problems which can be minimized using the contextual approach described in the previous paragraphs or by implementing mechanical cooling.

Table 13: the possible amount of windows utilizing mechanical ventilation with heat recovery.

orientation	north	south	east	west
Window area (m^2)	9	43	9	9
Wall area (m^2)	36	2	40	40

Table 14: the energy consumption with twice the amount of windows compared to the original layout.

Energy consumption	kWh/m^2
Heating	60,6
Electrical power consumption	3,2*2,5
Overheating (mechanical cooling)	19,5
Total	86,8

The building is subjected to a considerable amount of overheating which would result in a high level of discomfort for the inhabitants.

By increasing the overhang to 2000 mm the problem of overheating is actually disposed of (Table 15). This converts the southern façade into a patio.

Table 15: the energy consumption with twice the amount of windows, with the overhang increased to 2000 mm

Energy consumption	kWh/m^2
Heating	72,1
Electrical power consumption	3,2*2,5
Overheating (mechanical cooling)	0
Total	80,2

The dwelling no longer qualifies as a low energy class 2 building. The layout of the building differentiates from the original layout with a substantial larger amount of windows and a patio to the south.

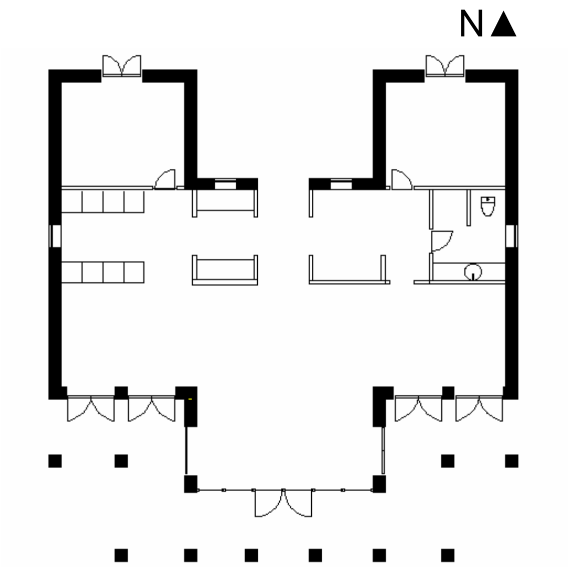

Figure 3: Modified floor plan, with increased amount of windows to the south, west and east. Not to scale

By implementing further technological measures such as solar heating the total energy consumption can be diminished even further.

6. THE MATERIAL BASED APPROACH

Another course to follow is to use the technological measures to make the modified layout from paragraph 5.1 more energy efficient. This could be accomplished by increasing the amount of insulation used, by minimizing thermal bridges and by increasing the air tightness of the building. By increasing the amount of insulation the building can be modified to comply with the lover energy classes. Increasing the amount of insulation is often seen as problematic from an aesthetical point of view. This would produce thicker and heavier walls, roofs and decks. On the other hand the new building code does not distinguish between how much insulation you use in the walls compared to the roof or deck as long as the minimum values are met. In consequence you could have walls just complying with the minimum consumption while the floor and roof is packed with insulation (Table 16).

Table 16: decreasing the *U*-values of the original layout in order to comply with energy class 1. Insulation is primarily placed in the floor and roof. The *U*-value for windows includes frame and is a mean value.

Insulation	wall	floor	roof	window
U-value (W/m^{2}K)	0,18	0,09	0,09	1,1
Insulation mm	210	400	350	

Table 17: the energy consumption with increased insulation. The modified layout from paragraph 5.1 now complies with low energy class 1.

Energy consumption	kWh/m^2
Heating	35,2
Electrical power consumption	3,2*2,5
Overheating (mechanical cooling)	0
Total	43,3

The approach of insulating specific parts of a dwelling is especially effective when considering the modified design with the larger amount of windows (Table 14 and Table 15) and consequently smaller wall area. Increasing the insulation in the walls will have an insignificant impact on the overall energy performance of the dwelling as a whole. The amount of blank wall only constitute one fifth of the overall building envelope whereas the roof and floor each compromise a third. The windows roughly constitute half of the vertical building envelope and the heat loss through but the heat loss through the windows actually represent on third of the entire heat loss through the building envelope.

7. CONCLUSION

This paper considers three different approaches to making an already designed building comply with the new energy demands and even comply with some of the low energy classes in Danish dwellings. The first presented is modification of the orientation and amount of windows, which shows that modifying the layout of the building according to the build environment can generate significant reductions in heat consumption. Another step is to implement technological means in order to reduce the amount of energy used to heat the dwelling (in this paper represented by mechanical ventilation with heat recovery): The last subject considered in this article is the consequences of changing the ways different parts of a dwelling are constructed. By increasing the amount of windows increasing the insulation in the walls will have a decreasing impact on the primary energy consumption. The amount of windows to be used is

However if the consequences of the contextual approach are counteracted as in this paper you are required to use technological or material based means to meet with the new demands. It is possible to add technological devices to make a poorly orientated or designed building more energy efficient and thus decrease the operational costs and possible the lifecycle costs. However this will add to the building costs. Implementing the considerations depicted in this article, the operational costs could possible be significantly reduced without having to add considerably to the building costs along with an improvement of the indoor climate.

If the same methodology as depicted in this paper is implemented in the initial design considerations, expensive technological steps could be avoided. By using the tool provided by the building authorities which is used throughout the entire process of this paper, the designer has a suitable tool to benefit from early in the design process.

This paper also demonstrates a need to rethink the ways traditional Danish dwellings are built in order to provide room for the increased amount insulation necessary in all houses. By applying the considerations of where to put the extra insulation early in the design process, the designer is enabled to take the aesthetic impact of more insulation into account in the initial design concept.

ACKNOWLEDGEMENT

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