BOLIG+ - an energy neutral multifamily building

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Synopsis

BOLIG+ is a Danish concept for energy neutral houses based on five dogmas: 1) energy neutral incl. household energy, 2) intelligent and user-friendly, 3) flexible in daily use and over time, 4) good and healthy indoor climate and 5) high architectural quality and adaption to local context.

The first BOLIG+ building will be a 10/6 storey multifamily building with 60 apartments and a total floor area of 7000 m². Five teams were asked to submit a proposal to a project contest. The five teams were found in a pre-selection among 44 interested teams. The winning team, TEAM+[1], was appointed in September 2009.

The building will be build on normal commercial conditions which made the task of designing the building rather difficult as the location wasn't well suited for solar energy and the price of district heating is very low in the area. However, the five teams came up with five projects which easily may be transferred to other locations. The winning team utilized a low energy prefab system for the building envelope in combination with energy savings of the household energy demand plus a heat pump, PV and PV/T collectors.

It is the aim that the construction of the building will start during 2011. Due to the prefab building system the construction time is foreseen to be less than one year.

1 Dogmas

BOLIG+ is a dogmatic building concept for residential buildings in any scale, ranging from single family detached houses to blocks of flats. The five dogmas of BOLIG+ have been developed in cooperation between several Danish organizations and institutions in the BOLIG+ group, in order to facilitate the development of homes for the future. The dogmatic concept can easily be extended to other usages of buildings as well. The five dogmas a BOLIG+ building must meet are:

- Energy neutral on annual base, including electricity for appliances;
- Intelligent and user-friendly;
- Flexible in daily use and over time;
- Good and healthy indoor climate;
- High architectural quality and adaptation to local context.

The dogmas concerning intelligence, user friendliness and flexibility are equally important in order to maintain the energy neutrality over time. The dogmas concerning good indoor climate, architecture and

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adaption to the local context are mandatory in order for the concept to be widely accepted by the users and the public.

1.1 Energy neutral on annual basis

The dogma energy neutrality on annual basis is a necessary demand for future homes in a reality where energy is a scarce source and climate changes threaten to change our way of life. In BOLIG+ terms, energy neutrality on annual basis, means that the home must meet the energy frame requirements of the Danish Low Energy class 1 (LE1) as stated in the Danish Building Regulations 2008 [3], but without production of electricity. The maximum allowed energy consumption to be able to meet the LE1 requirement is:

$$Q < 35 + \frac{1100}{A} \quad [\text{kWh / m}^2 \text{ per. year}], \text{ where A is the gross floor area.}$$ [2]

Q is the gross energy consumption for heating, cooling, ventilation, domestic hot water, heat production and distribution, electricity for operating the building (multiplied by 2.5) plus possible penalty for excess heat (fictive cooling energy consumption if indoor temperature exceeds 26 °C). This definition is valid for a standard indoor temperature of 20 °C. In the BOLIG+ dogma, the indoor temperature must be increased to 22 °C in the calculation. Furthermore, the standard domestic hot water consumption must be increased from 250 to 375 litres per year per m^2 heated gross floor area. This increased numbers for indoor temperature and domestic hot water consumption are being regarded more realistic than the standard values.

Compliance with the requirements for the LE1 energy frame must be proven by calculations using the Be06 [4] building regulations compliance tool.

Furthermore, the building must deliver the same amount of energy and at least of the same quality (exergy) and usability of energy delivered to the public grids as the building consumes over the year. In reality this means that thermal energy bought from the local district heating grid during winter time can not be replaced by hot water e.g. heated by solar during summer. Hot water does not have any value in the district heating grid during summer because of excess heat at this time of the year due to the primary purpose for the district heating grid which is combined heat and power production.

Finally the household energy demand must be part of the overall energy neutrality for the building. Electricity for household appliances has though in the BOLIG+ definition been limited to the most optimum electricity consumption for a Danish standard household, meaning 1700 kWh per flat in a block of flats (2100 kWh per year in single family houses).

The BOLIG+ dogma do not request any special requirements for the thermal envelope for choice of building materials or products having a certain accreditation of performance. The energy frame sets the targets for the envelope and the installations in combination.

1.2 Intelligent and user-friendly

Dwellings of the future have a need for monitoring, data collection, and demand control to become energy neutral on an annual basis. In BOLIG+ it will be necessary to include control of electricity as this will be a major part of the total energy consumption in the dwelling.

BOLIG+ must help the users in being energy neutral – either in a passive robust way or via intelligent components or a combination of both. A monitoring system should create awareness on the energy performance of the house and inspire the user to save energy. The monitoring system may be part of a home automation system which also controls the installations and household electricity demand in order to minimize the energy demand while increasing the comfort.

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[2] In the 2010 recast of energy requirements of the Danish Building regulations, the energy frame for LE1 have changed to $Q \le 30+1000/A$ (for residential buildings) and an energy factor on district heating of 0.8 have been introduced. For this actual building size in a district heating area this means an increased energy frame from 35.2 to approximately (depending on the fraction of heat to electricity) 36.7 kWh/m² per year.

1.3 Flexible in daily use and over time

BOLIG+ is the physical frame for possible unconventional family structures like; divided families, long distance families, net families, miniature shared living as well as traditional families. Flexibility means that the dwelling must be able to adapt to the number of residents in the dwelling. It must be adaptable for new families, families with large kids and elder people with limited mobility. This puts large requirements for resource optimal constructions.

BOLIG+ must meet requirements for limited consumption of resources in case of re-construction and maintenance and thus meet the requirement for flexibility over time. Furthermore it is important that replacement of parts of components can be made easily as different parts of the building have different physical and technological life time. BOLIG+ focuses on flexibility for replacing individual building components without damaging other parts of the building.

A flexible thermal envelope may be designed in a way that the surface of the building can adapt to the daily and annual rhythm as well as different influence from sun, rain and wind. The thermal envelope may close, e.g. during nights or winter and open in other periods with free heating gains. In heating periods there should be focus on utilization of passive solar energy.

1.4 Good and healthy indoor climate

The goals regarding indoor climate in BOLIG+ is to design and construct an in all ways healthy building with a good and healthy indoor climate on the following focus points:

- Daylight / artificial light;
- Atmospheric indoor climate;
- Temperature;
- Air quality;
- Choice of materials;
- Acoustics and sound.

All this must be achieved by the least possible CO_2 emission.

The indoor climate depends on a number of factors that are closely connected to decisions related to energy consumption, which are made during the initial phases of the design process: Daylight / artificial light, atmospheric indoor climate, temperatures, air-quality, choice of materials, acoustic and sound are all parameters that should be optimized in the design phase. Important elements are thus optimization of daylight, control of artificial light, passive solar utilization, use of sustainable and healthy building materials, all without negative influence on acoustics.

Location in relation to sun and daylight, need for shading and neighbouring buildings influence on shadows and glare should be handled in the design of BOLIG+. First of all the dwelling must have a high daylight factor via optimal orientation and disposition of functions, rooms, and light inlets must be designed to lead the daylight deep into the building. The stable light from North must be utilized and the sun from South as a source for passive heating, though avoiding the risk of over heating.

1.5 High architectural quality and adaptation to local context

BOLIG+ must be designed in an idiom that supplement the surroundings and is sustainable over time and expresses the period of construction. BOLIG+ must by its proportions meet the basic human expectations to harmony and balance – while at the same time hold surprises, new ideas and challenges. BOLIG+ must be able to take part in the local energy infrastructure and must not set special requirements to the surroundings.

BOLIG+ must be constructed from materials that are technically suited for the local environment and that gives positive visual properties – while at the same time materials with minimal negative influence on the working environment, indoor climate and surrounding environment.

2 Architectural contest

For the first BOLIG+ building a location in Aalborg (the fourth largest town in Denmark) was selected. The location is very beautifully situated at the north bank of Aalborg Fjord and very close to the town centre. It is thus a very attractive location. However, the local development plan for the location did make it difficult to fulfil the requirement of energy neutrality – e.g. the height of the building towards the fjord should be 10 stories (facing South-West) while it towards North-West could be only 6 stories high which means that the front house towards the fjord shades the roof of the back house. Another problem is that Aalborg has very cheap district heating from waste heat from local cement and electricity production which makes is difficult to make energy neutrality affordable at this location. On the other hand if the energy neutrality demand can be met here it can be transferred to any location.

The local development plan outlines a building with 60 flats and a total gross floor area of 7,000 m².

The project contest form [1; 2] was chosen in order to obtain high quality proposals with a large variety of solutions. For this reason the contest was divided into an open prequalification followed by a main contest – the latter with 5 selected teams.

The contest was announced on two conferences in October and November 2008. Teams were asked to sign up for the prequalification. It was emphasized that the teams should be interdisciplinary – i.e. contain engineers, architects and manufactures - and international partners in the teams would be welcome.

44 teams signed up for the contest although the international crises had not at that time hit the Danish building industry and all were very busy.

Five competent teams were selected and the main contest started by a workshop in March 2009. The deadline for proposals was the end of May 2009. The group behind BOLIG+ had in advance worked out a detailed description and a tool for the documentation of the energy neutrality of the proposals. In order to make sure that the teams understood the terms of the contest and the tool, each team was offered two consultations with experts from the BOLIG+ group.

2.1 The winning project

The winner of the project contest was announced in September 2009. The winning team, TEAM+, consists of eight partners – architects, engineers and manufactures. The team utilizes the following in their energy concept:

- considerably reduction of the energy demands compared to the Danish building code Low Energy class 1 (LE1) by means of passive measures and solar heating. Energy demand of 13 kW/m² compared to the LE1 demand of approximately 35 kW/m²;
- reduction of the electricity consumption for light and appliances compared to country average;
- intelligent systems supporting users to minimize their consumption;
- combination of mechanical and natural ventilation;
- utilization of a heat pump based on ambient air and solar energy;
- utilization of thermal solar heat in the form of PV/T collectors – 200 m² on the roof;
- utilization of PV: 600 m² (+ 200 m² PV/T) on the roof and 900 m² on the parapets.

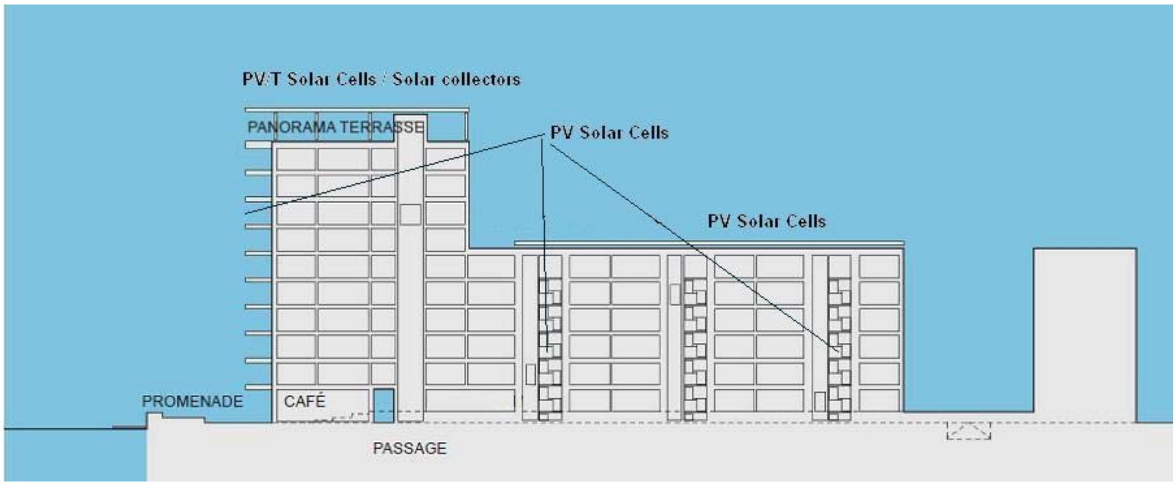


Figure 1. Cross section of BOLIG+ winning project. Solar cells (200 m² PV/T and 600 m² traditional PV) are located on the roof and 900 m² PV on the parapets.

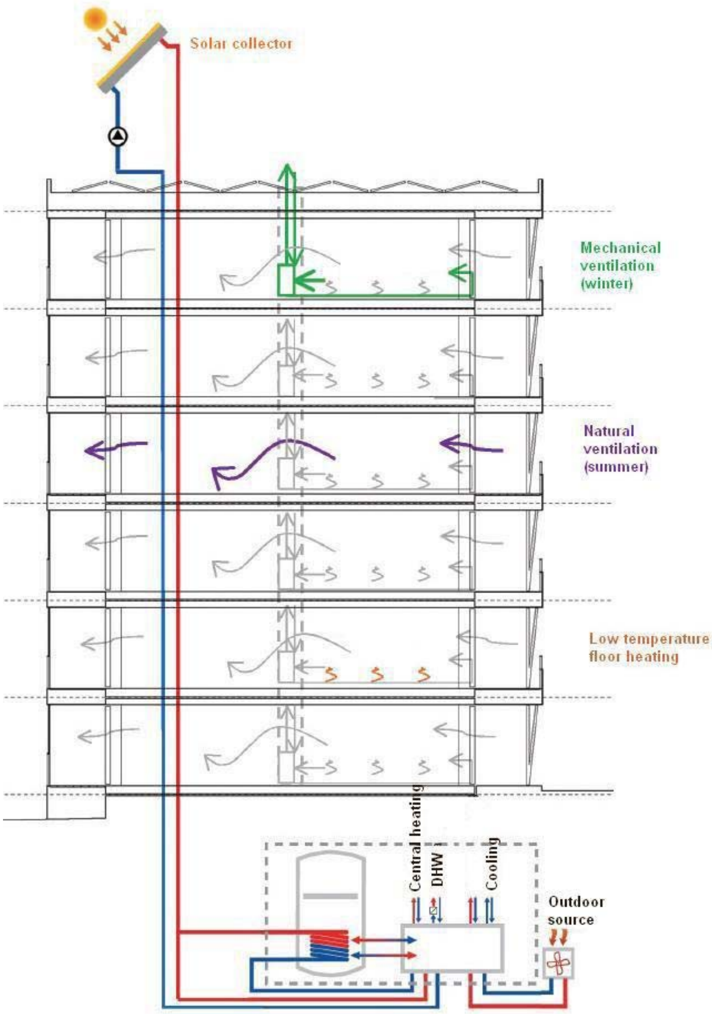
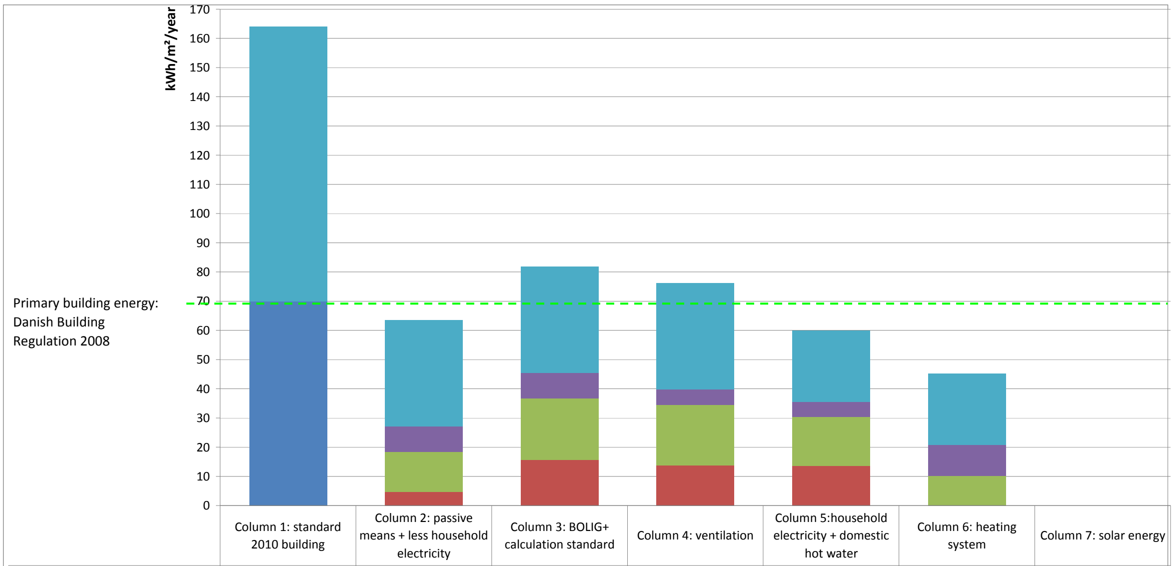


Figure 2. Energy systems in BOLIG+. There is balanced mechanical ventilation with heat recovery during the heating season while natural ventilation is being used during summer periods.

The approach to reach energy neutrality has been: 1) reduction of the energy demand, 2) utilization of energy efficient installations and finally 3) utilization of renewable energy systems to cover the remaining energy demand of the building and households. This is shown graphically in figure 3 and each of the columns are described in detail in the following.



	Column 1: standard 2010 building	Column 2: passive means + less household electricity	Column 3: BOLIG+ calculation standard	Column 4: ventilation	Column 5:household electricity + domestic hot water	Column 6: heating system	Column 7: solar energy
Electricity: household	94	36,4	36,4	36,4	24,4	24,4	0
Electricity: installations		8,75	8,75	5,25	5,25	10,7	0
Domistic hot water		13,7	20,9	20,9	16,7	10,2	0
Space heating		4,7	15,8	13,7	13,7	0	0
Max building energy: Building code	70						

Figure 3 The 6 steps from the today Danish standard to energy neutrality.

Column 1

The requirement of the Danish Building Regulation from 2008 is a max annual primary energy use of 70 kWh/m² per year (electricity is multiplied with a factor of 2.5) for running the building. In the 2010 recast of the Danish Building Regulations it is foreseen that the max annual energy use for running such a building will be lowered to 52.7 kWh/m² per year.

The average electricity use for households is in Denmark 1,423 kWh/year per person. As it is estimated that 3 persons in average will live in an apartment this gives a consumption of 94 kWh/m² per year after being multiplied by 2.5.

Column 2

Passive means – reduction of the heat loss through the thermal envelope based on the Passive house principle: U-value of 0.1 W/m²K for the walls, 0.07 W/m²K for the roof, 0.08 W/m²K for the ground deck and 0.9 W/m²K for the windows. Thermal bridges have been nearly eliminated and the building is very airtight. Focus has been put on utilization of passive solar energy yet avoiding overheating and optimization of daylight. The building will be constructed of highly insulated and airtight prefabricated modules of up to 90 m² from the company Bau-How.

One of the demands in the contest was that the electricity demand of the households should be reduced from 4,500 to 1,700 kWh/flat per year. This can be done by only using the best white goods (A+ and A++) on the market. In the winning project old knowledge has further been brushed up and applied in the form of a natural cooled larder and a natural ventilated drying cabinet. An intelligent system reduces the standby losses and informs the users on the energy performance of their flat. This gives an electricity consumption of 36.4 kWh/m² per year after being multiplied by 2.5.

Column 3

The Danish Building Regulation 2008 prescribe that the energy demand of a building should be calculated based on a set of standard values – e.g. a room temperature of 20 °C, a domestic hot water demand of 250 l/m² per year and a internal load due to appliances of 3.5 W/m². However, in real life these values are most often different. So when calculating energy neutrality in a BOLIG+ context the room temperature has been increased to 22 °C, the domestic hot water demand has for this building been increased to 375 l/m² per year and the internal load for appliances has – due to the reduction of the household electricity demand from 4,500 to 1,700 kWh/year per flat – been reduced to 1.71 W/m². This increases the energy demand of the building as seen in column 3. But it gives a more realistic picture and is thus expected to give better agreement between calculations and measurements.

Column 4

The energy demand of the installations has been optimized. Decentralised ventilations systems – one for each flat – have been applied in order to reduce the SFP-value of the ventilation. The ventilation systems are equipped with a counter flow heat recovery unit with high efficiency. In order further to reduce the energy demand for ventilation, demand controlled ventilation is utilized – without compromising the air quality. During the summer a large part of the ventilation will be natural which lead to further savings in the electricity demand for ventilation.

Column 5

The electricity demand for household has been reduced by applying gas cookers instead of electrical cookers and by leading hot water to the washing machine and dishwasher. The energy demand for domestic hot water has been reduced by applying water saving fittings and by minimizing the heat loss from the hot water installations.

Column 6

The heating system consist of a solar heat pump which combine the solar heating and heat pump technology in a new an innovative way. Solar heat is utilized for domestic hot water and as heat source for the heat pump. This increases the efficiency of both the solar heating system and the heat pump.

Column 7

The remaining energy demand is covered by solar energy. Due to the requirements of the local development plan for the location it is a non trivial task to harvest the necessary solar energy in order to make the building energy neutral. A large part of the surfaces have to be utilized and most of them have a non optimal orientation and tilt.

The PV panels on the roofs are mounted as flat as possible – with at tilt of only 15° and facing East or West – see figure 2. In this way the panels do not shade each other and the PV area can be optimized. The production will be 30 % less than from an optimal orientation and tilt. PV panels are further located on the parapet of the balconies facing South and South-West. In total 1,700 m² of PV panels is necessary to cover the remaining energy demand of the building and make it energy neutral.

200 m² of the solar panels on the roof are PV/T solar panels that combine solar collectors and PV panels. This optimizes the utilization of the available area on the roof. The performance of the PV cells is further increased a bit due to the cooling via the solar collectors behind them. The heat from the PV/T panels is used for domestic hot water and as heat source for the heat pump as described under column 6.

3 Project status

The global economic crisis has influenced the activity in the Danish building industry, and almost no new construction work is being initiated. Negotiations are on its way, and there is still hope that the building will be constructed on normal marked conditions. For the time being it seems that there will be a consortium of a private builder and a social housing association. The private builder will construct and sell the tower part of the building close to the water front (high value due to the location and the direct view to the water) while the social housing association will construct and rent the lower part of the building. No matter the ownership, the entire building complex will be constructed according to the BOLIG+ dogmas.

4 Measurements

In order to evaluate the performance of the building and the behaviour of the users a measuring system will be installed. In this way it will not only be possible to judge if the dogma about energy neutrality is meet but also to gain valuable information on how this type of building influences the public utility grids.

5 Acknowledgements

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6 References

[1] BOLIG+. The contest programme. www.boligplus.org.

[2] BOLIG+. The reflection of the jury. www.boligplus.org.

[3] Danish Building Regulations, 2008.

[4] Buildings energy consumption. (Only available in Danish: Bygningers energiforbrug). SBi direction 213. Aggerholm & Grau, 2008. Danish Building Research Institute, Aalborg University.