Architecture and Energy. Strategies for a Changing Climate.

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INTENT AND PURPOSE.

This paper aims to further integrated design of low energy buildings with high architectural quality, buildings that are geared to a changing climate.

A precondition for qualified integrated design is a holistic approach that on the technical side covers all sorts of energy used to construct, run and use modern buildings, and on the humane side includes functional, social and aesthetic aspects of modern living.

The paper shows how qualified integrated design up till now has not been achieved. It shows how a narrow focus on the solution of sub-problems may result in big problems elsewhere in the complex system of designing buildings. The paper concludes that if low-energy houses shall be geared for a changing global climate, they must include a strong focus also on non-heating needs and on electricity-related architectural aspects: Building depths, spatial organization, daylight, natural ventilation and solar cells.

In order to get a truer, well-focused perception of how to design sustainable buildings, one need to know basically what is more and what is less important among all the energy-related environmental issues.

One of the main purposes of this paper is therefore to provide some sense of essentiality.

BACKGROUND.

The paper deals with Danish conditions which may differ from those of other countries when it comes to climate, natural resources, patterns of settlement, building traditions, education of builders, energy supplies and ways of living and working, just to mention some of the most important determinants. However, it can be assumed that many of these factors will be similar in countries in northern Europe with a maritime climate and an effective regulation of heat consumption in new buildings, and where the transition from an industrial to an information- or knowledge-based society is well-developed.

Denmark has a coastal climate with relatively high humidity and warm winters. The warm winters means little snow and therefore lesser reflected daylight than in other Nordic countries.

There is clay and lots of lime in the Danish underground providing raw materials for bricks and concrete. Since medieval times the wood resources has been more or less sparse.

The Danes prefer to live in detached single-family houses. About 2.7 million or half the population does so, and many of those living in flats would choose a single-family house if they could afford one[1]. This is not a sustainable modern way of settlement. Detached houses use lots of land causing wide-spread cities, which again causes much more motor-driven transport than denser types of settlement[2]. The necessary infrastructure and attached environmental impact per house unit also grows while spreading the cities, so does the loss of heat in district heating supply systems. And not least, the detached house has a far greater heat loss per unit floor area than denser types of housing.

This paper will not dig further into the environmental questions related to city planning, but the planning perspective should not be forgotten, especially as the major part of those houses being promoted as 'sustainable' or 'environment-friendly' are actually single-family houses.

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[1] http://www.statistikbanken.dk/BOL66

[2] Næss, Petter m.fl: Energibruk til transport i 22 nordiske byer. Norsk Institutt for by- og regionsforskning, 1994.

The Danish building tradition is about brickwork. The great Copenhagen conflagrations of the 18th century during which most of the medieval quarters burned down, caused a move from half-timbering to brickwork constructions in the cities. And using up the last Danish forests in the beginning of the 19th century caused the same development in the rural areas[3]. From around 1850 to around 1950 practically all Danish buildings were made of bricks, in the beginning mostly of red bricks made from upper layers of clay from which the lime had been washed out, later on of yellow bricks from lower layers of clay still containing lime, causing the yellow color. In the 1950's concrete constructions began to take over in multi-storey buildings and dominated till the 1970's. Concrete still dominates as bearing system, while the outer wall (and with that the architectural expression) has been replaced by a multitude of coverings. Also in single-family houses lightweight concrete dominates as bearing construction, while bricks are the still preferred for facades.
Most Danish architects are educated in the beaux-art tradition. Kunstakademiets Arkitektskole in Copenhagen has since 1754 been part of an art academy sharing buildings with sculptors and painters, and has only recently moved to buildings of its own.
Aarhus Arkitektskole opened in 1965 as an independent institution, but is as the Copenhagen school placed under the Ministry of Culture, and has only one or two engineers employed.
Only the Department of Architecture and Design at Aalborg University belongs to a technical faculty and is placed under the Ministry of Science. The Department has integrated design as a profound part of its teachings. But the first students were enrolled in 1997 and the candidates, 'civil engineers specializing in architecture' still have not left an influential mark on Danish architecture.

ATTEMPTS AT LOW ENERGY ARCHITECTURE 1973-2006

The first oil crisis in 1973 marks a turning point in Danish history including its methods of building. The then pro-Israeli Danish society was during the Yom-Kippur War met by an Arab oil-boycott that displayed the vulnerability of a country where over 90% of the energy consumption was covered by Middle East oil. Pre-insulation of buildings, installation of wood burning stoves and some initial small-scale experiments later to become windmill industry were in 1977 followed by new Building Regulations with two new important rules[4]: The total area of doors and windows could not exceed 15% of the total floor area. And thermal bridges could only be accepted to a very limited degree.
The first rule meant that for the next eighteen years buildings with limited daylight conditions were built. Those modernist dreams of glass facades that had - during the sixties - slowly become reality not only in office buildings but to some degree also in housing had now crashed, leaving once again the window as a hole in a wall. There was a way to get around this obstacle: Rooms that were not heated could have lots of glass. This resulted in thousand of so called non-heated winter gardens and other glass extensions of existing houses. Practical speaking all so-called ecological houses of this period is supplied with a winter garden meant to pick up solar heat that can be transported to the heated parts of the house, thus reducing the need for supplied energy. The winter garden became a crucial ecological element and symbol.
In 2001 a survey was being carried out that revealed that these so-called ecological houses with winter gardens had a considerably larger need for heat supply than ordinary houses[5]. An obvious reason could be the fact that Danes long for daylight also on the darkest days, and heated winter gardens is a tempting possibility.

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[3] Fritzbøger, Bo: Kulturskoven. Dansk skovbrug fra oldtid til nutid. Gyldendal, 1994.
[4] Bygningsreglement 1977. Boligministeriet, 1977.
[5] Dollerup, Hans m.fl: Passiv solvarme i nyere danske boligbebyggelser – erfaringsopsamling og anbefalinger. Århus: Dansk Center for Byøkologi, 2002.

The second rule concerning thermal bridges meant that the outer walls outer leaf and inner leaf could no longer be attached to each other, as they had been around doors and windows, at the roof cornice and sometimes at the foundation. This meant that the outer leaf was in general no longer part of the bearing system but functioning primarily as a rain screen. Brickwork walls are not the optimal rain screen, and the new rule accelerated a development towards multi-layered outer walls, each layer serving its specific purpose. As rain shields can have many forms, the possibilities for architectonic expression were widened, and the old modernist dogma that a building should express its construction became redundant. Postmodernism and its ‘anything goes’-attitude were the talk of the town. But the amount of construction failures increased as new multilayered constructions involving a multitude of materials, joints and building trades open up for more mistakes than well-proven brickwork.

During the 1980’s windows with lower U-values were developed, and the so-called energy-windows insulating twice as good as the old double-layered windows were introduced. At the same time especially architects argued for better daylight conditions in buildings and several groups argued for recognition of the benefits of passive solar heat.

The new Building Regulations of 1995 were at the same time stricter and more liberal concerning use of energy, and still totally focused on space heat consumption[6]. The accepted maximum U-values for the building envelope were lowered, especially concerning the windows. At the same time the allowed area of windows and doors were increased from 15 to 22%. But also two alternative calculation-methods were now in use. The first was the ‘heat loss target’, that allowed some U-values to go up if others were lowered so the overall heat loss would be the same. The second was the ‘energy target’ which included heat loss due to transmission and ventilation and heat contribution in the form of passive solar heat and internal heat gains. The effect of heat accumulation in the thermal mass was also included. Using the energy-target method, there were no restrictions on the amount of windows, as long as the calculated heat consumption did not exceed a given limit corresponding to the consumption of a standard house.

Those architects, whose visions of glass facades had been suppressed for almost two decades, quickly caught the opportunity. Beside strong modernism images and a legitimate wish for better daylight conditions in buildings, passive solar heat had gained a strong reputation for being ecological, so the urge and arguments were many. In 1996, on the first big building exhibition after the new regulations, a dwelling built exclusively with triple glazed facades was erected (the test family had to wear sunglasses, it later showed). The house was thought of as low energy house and the heat consumption was calculated to 50% of the energy target. It was later measured to 32% above the frame[7]. The same year, a national architectural competition called Eco-house 99 was arranged. Five out of six proposals had large glazed areas facing south-southwest, and the two winning projects had almost 100% glass on the southern facades**.** One of the two showed big problems with overheating when being used, and the other one showed that the actual use of heat in such solar houses is very dependent upon the habits of the occupants[8], [9]. Residents in these projects have reported on temperatures between 30 and 45 degrees Celcius in the 1st floor rooms during the summer months! Calculations later carried out by the Danish Building Research Institute showed that the reductions in primary energy consumption were very limited, partly because it is difficult to utilize so much

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[6] Bygningsreglement 1995. Bygge- og Boligstyrelsen, København 1995.
[7] SBi-rapport 317 (1999): Det højisolerede glashus. Egebjerggård, Ballerup.
[8] Dollerup, Hans m.fl (2002): Passiv solvarme i nyere danske boligbyggerier – erfaringsopsamling og anbefalinger. Dansk Center for Byøkologi.
[9] Hans Bjerregård Rådgivning ApS (2001): 12 Byøkologiske forsøgsbyggerier – Erfaringer og anbefalinger. Erhvervs- og Boligstyrelsen.

passive solar heat, partly because there is a great heat loss through big facades, and partly because the energy embedded in glass production is relative big[10],[11] **.**
Besides the ecologically ambitious housing projects a lot of glass-walled office buildings were erected in the late 1990's. Terrible indoor climatic conditions and energy consumption three times as high as regular offices – mostly due to immense cooling demands covered by electrically driven cooling systems – were a common result[12] . The glass offices looked modern but were not geared for the energy conscious 21st century.

The last three decades of the 20th century show many conscientious – both governmental and architectural - attempts at creating buildings with lower heat consumption. The lower U-values of the building envelope have had markedly good effects, but the regulation of window-area, sun and light has in general failed both regarding indoor climate and energy consumption. The positive effects of big glass facades have been largely overrated, perhaps due to the non-calculating approach of beaux-art architects: If windows can make passive solar heat which is good, then big glass facades is even better and more ecological. Well, not necessarily so.
During the same decades the Danish energy supply-system has changed radically. Fossil fuels are still the main source, but electricity plants and district heating plants have been united to 'combined heat and power plants' (CHP), meaning that the heat loss from making electricity can now be utilized for district heating. Only around 40% of the energy used for electricity production comes out as electricity, the rest becomes heat. Only very few Danish buildings are heated by electricity.
Together with better insulation of existing and new buildings, this means that the total amount of primary energy for heating have gone down, though thousands of new buildings have been built. It also means that the relative importance of heating has decreased compared to other energy consumptions.
From 1975 to 2005 the Danish population increased 7%. The gross floor area of all types of dwellings increased approximately 50%. But the primary energy consumption for heating went down with 20%, while the primary energy use for electricity went up with 70%[13]. In a typical terraced house built according to regulations the primary energy use for electricity has been bigger than for heating since the late 1990's[14].
When it comes to office buildings the tendency is even stronger. From 1975 to 2005 the gross area of office and administration buildings has increased 55%. In the same period the primary energy use for energy consumption has gone up 10% while the use of electricity has gone up 160%. This big increase is due to a big growth in IT-related technologies, but also to the construction of very deep building with big glass facades and open office landscapes using lots of electricity for artificial lighting, cooling and mechanical ventilation. When looking at a typical new office the primary energy for heating and hot water has decreased 60% from 1975 to 2005. The use of electricity has gone up 55%. And since the late 1970's the energy used for electricity exceeds the energy for heating[15]. The role of electricity driven functions has switched and is very critical. Decades ago the heat loss from electrical appliances and artificial lighting was welcomed as a supply for heating the cold buildings. Today, in well-insulated buildings internal heat loss is more likely to cause an increased need for cooling, using lots of electricity.

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[10] Marsh, Lauring & Petersen (2000): Arkitektur og miljø. Form konstruktion materialer – og miljøpåvirkning. Arkitektskolens Forlag.
[11] Statens Byggeforskningsinstitut (1999): ØKOHUS 99. Miljørapport 1. Ikast og Århus. By- og Boligministeriet.
[12] Sinding-Jensen, M. (2002) Glas skal bruges med omtanke. *VVS og El Horisont*, nr. 11, pp. 22 - 23.
[13] Energistyrelsen, 2007.
[14] Marsh, Larsen & Hacker: Bygninger Energi Klima: Mod et nyt paradidme. Statens Byggeforskningsinstitut 2008.
[15] Do.

The increased use of energy in closely linked to inexpedient architecture and lack of integrated design. If energy consumption is to go down, architecture must back up this intention rather than acting on its own.

RECENT ATTEMPTS AND GUIDELINES

In the Building Regulations of 2008, the rules concerning energy have once again been changed profoundly. Actually the rules were imposed already in 2006 as a consequence of a EU-directive on the energy performance of buildings[16]. The rules take their starting point in two premises: To assess the whole and the primary energy consumption. Included is the needed energy for heating, cooling, hot water, lighting (not in dwellings), building services (like pumps and ventilation) and the system losses (heat loss from internal plant, pipe work etc). On the other hand building integrated energy production from solar heat and solar cells is included in the assessment. For calculated overheating going over 26 degrees, the electricity for running a standard cooling system to eliminate the overheating must be included in the assessment.
The primary energy consumption deals with the fact that most types of energy have an energy loss during production and distribution. The production of electricity has an effectiveness of only 40%. Therefore electricity needs are multiplied by 2,5. Gas, oil and district heating is multiplied by 1,0. The Building Regulations deals with two classes of low energy buildings: Class 2 equals a consumption that is 75% of the energy frame, while class 1 equals 50% of the energy frame. The experiences with the new low energy buildings are still pretty limited. This is partly due to the fact that the Danish liberal government which took over in 2001 immediately cut away that support for experimental and demonstration buildings and follow-ups such as the screening of user-experiences, that had characterized the 1990's.
Instead this paper will focus on some calculations and reflections being part of a research project and published in 2006 with focus on the interplay between architecture and energy seen in relation with the new energy rules[17]. The publication, *Architecture and Energy*, is divided into four small chapters: Daylight, Passive Solar, Construction and Technology. In each part a respectively deep and light dwelling are scrutinized followed by a deep and a light office.

As daylight conditions has suffered under previous attempts at making low energy buildings, the first chapter of this publication dedicated to good architecture started out defining daylight quality as a matter of not only sufficient daylight (preferably an Average Daylight Factor about or over 5%) but also a matter of the geometry of light, where a combination of diffuse and direct daylight is in many cases preferred. Not least, the dispersion of daylight plays an important role: If some parts of a room are pretty dark while other parts - for instance close to big windows – are strongly lit, the human eye will find it uneasy to adapt - and get tired. The measurements have three parameters: Firstly: The proportion of the room, or to be exact the distance from the floor to the upper edge of the window compared to the depth of the room. Secondly: The percentage of the façade that is made of glass: The bigger the percentage, the more light is admitted. Thirdly: The glass type. Is it double or triple glazed, is it solar shading glass or not?
A main point of the chapter Daylight is that <u>rooms with small depths can obtain a good average daylight level of 5% with far lesser window area than a deep room</u>. Light and well-lit rooms can be designed with moderate glass areas corresponding to 30 to 50% of the façade. A second point is that <u>the dispersion of light is much better if rooms are not too deep</u>, thanks both to the limited depth and to the more limited window area.

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[16] Europa-Parlamentets og Rådets direktiv 2002/91/EF af 16. december 2002 om bygningers energimæssige ydeevne.
[17] Marsh, Larsen, Lauring & Christensen: Arkitektur og energi. Statens Byggeforskningsinstitut, 2006.

A third point is that good architecture and the regard for good daylight conditions can be united. Advocating moderate window areas does not mean a return to the peephole architecture of the past. There a many examples where moderate use of glass has caused good architecture - indoor and outdoor.

The next chapter, Passive Solar, investigates what happens concerning energy consumption if the average daylight factor is increased from 2% to 5 % in the deep and the light dwelling and in the deep and the light office. It also investigates what happens if the building is turned from facing south/north to facing east /west. In the deep dwelling and the deep office, in order to obtain a good daylight level the amount of glass area has to be markedly increased. This causes an increase in energy consumption due to more heating in the winter and more cooling in the summer. The less deep dwelling and office do not have to increase the glass area so much, why the energy consumption only goes up a small amount.
As a matter of fact, the light dwelling and office with a daylight level of 5% has the same consumption as respectively the deep dwelling and office with a daylight level of 2%. This shows that an optimized building shape may provide both better daylight conditions and lower energy consumptions.
In all four cases the energy consumption goes up if the building is turned from facing south/north to facing east/west. In the last case there is much solar heat during summer when it is not needed and very little solar heat in the winter when it is needed.
A main point of the chapter Passive Solar is that glass areas should be designed according to daylight demands. It does not any longer make sense to design buildings with enormous south facing glass areas to reduce energy consumption. Modern buildings are so well insulated and have so big internal gains from appliances that big glass areas may rather result in a costly cooling demand. Another point is that dwellings will benefit from windows being equally distributed between north and south. A third point is that office buildings should have bigger glass areas to the north than to the south. Eventually a light office building with reduced building depth could have office areas to the north and service functions to the south.

The chapter Construction incorporates in its calculations also the energy embodied in producing and using materials, though this kind of energy is not included in the Building Regulations. The chapter first investigates what happens if the U-value is lowered - meaning more insulation with embedded energy. When lowering the U-value from 0,25 to 0,10 w/m2K (the last corresponding to approximately 450 mm insulation) the energy savings related to heat consumption largely overrules the energy embedded in increased insulation. But when using more than 450 mm insulation the heat savings are marginal, the embedded energy gets big and the added result is close to zero.
The chapter also investigates what happens if the thermal mass of the building is increased: In general a high heat capacity is preferable even though more heavy materials, usually with high embodied energy, have to be used. The chapter also investigates where the heavy materials are most properly placed.
A main point of the chapter Construction is that the level of insulation of the building envelope can only be improved to a certain limit. Having reached a U-value of 0,1 w/m2K, further reduction will provide very limited savings in the total primary energy consumption. Another point is that light buildings with large facades may have reduced energy consumption. It is not necessarily an advantage to build deep compact buildings to reduce heat consumption. The calculations show that light, well-lit dwellings and offices with modest building depths, good room heights and therefore relatively large facades have less primary energy consumption than deep buildings. A third point is that a high thermal mass must be combined with reduced embodied energy for production of materials. In buildings with very low consumption, the energy embodied in materials

may be of the same size as the energy used for hot water - embedded energy actually counts. Heavy materials must be placed where they can best accumulate heat, for instance as inner walls or suspended floors. They should not be covered by lightweight linings or suspended ceilings.
Using heavy indoor materials and light materials with no thermal bridges for the building envelope is by the way a strategy that will strongly conflict with traditional Danish brickwork architecture.

The chapter Technology incorporates in its calculations the energy consumption of the previous chapters plus energy consumption for electrical equipment and domestic appliances. The chapter compares energy saving technologies focused on heat with technologies focused on electricity. The heat technologies include mechanical heat recovery with high efficiency, reduced consumption of hot water and increased insulation of heat installations. These technologies are later tested on the deep building types.
The electricity-focused technologies include natural ventilation and energy efficient building services, lighting and appliances. These are then tested on the light building types.
As such, the heat strategies save about 20% while the electricity strategies save about 30%. One reason is that efficient building services and appliances have lower heat losses which means less cooling demand.
Also building integrated energy production is calculated. Those parts of the south facades not covered with windows are on the deep buildings filled with 2/3 solar panels (making hot water) and 1/3 solar cells (making electricity). On the light buildings, 1/3 are solar panels and 2/3 are solar cells. The useable areas on the light buildings are bigger because of increased room heights and smaller windows.
The final results are that the deep, heat-focused dwellings save 20%, while the light, electricity-focused dwellings save 50% having a consumption of 75kWh/m2 for all energy purposes. The deep, heat-focused office saves 15%, while the light, electricity-focused office saves 60% having a consumption of 60 kWh/m2.
A main point of the chapter Technology is that natural ventilation and electricity savings can minimize energy consumption when the total primary energy consumption is estimated.
Another point is that building integrated solar cells may help create energy neutral buildings.
And a third point is that light buildings with modest depth, good room heights and large facades may better utilize electricity saving technologies, both because they are easier to ventilate with natural means and because they provide larger facades for more solar panels and solar cells.
The publication was distributed free to all 9,000 members of the Danish Architectural Association. The Association was also part of the project group behind the research project and the publication.

As the conclusions of the publication show, there are huge potentials in integrated design. Architecture and indoor climate can benefit and energy consumption be markedly reduced, if architectural and physical aspects are thought and worked together in an integrated process.

FUTURE STRATEGIES IN THE LIGHT OF GLOBAL CLIMATE CHANGE

As the above shows, much attention has to be paid to non-heating purposes, which means that the Building Regulations 2008 were on the right track widening the focus. The question is whether the focus is broad enough? Another question is what will happen in the light (and heat) of global climate changes: In what way will they change the focus and the needed strategies?
If we take a look at the current primary energy consumption in typical new terraced houses, heating stands for 23% while hot water is 12%, cooling 11%, building services 8%, lighting 7% and appliances are 39%. All

in all heat purposes are 35% while electricity covers 65%[18]. Out of the consumptions the current Building Regulations cover 54%, but not the last 46% (lighting and appliances). These tendencies are more radical when it comes to offices. The figures for typical new offices are that heating stands for 16%, hot water is 5%, cooling is 10%, building services are 6%, lighting is 9% and appliances are 53%. All in all heat purposes are 21%, while electricity covers 79%. Out of the consumptions the Building Regulations cover 47%, but not the last 53% (appliances). All together this calls for a much broader focus with stronger emphasis on electricity. The so-called passive house concept deals with minimizing the heat consumption to down below 15 kWh/m2 and the total primary energy consumption to 120 kWh/m2. But when a typical heat consumption is reduced 80% down to 15 kWh/m2, this means that the total energy consumption is reduced only 25%. By the way, a passive house in Denmark can reach the 120 kWh/m2 alone by traditional heat saving strategies, and without paying attention to savings on electricity. The light dwelling in the before mentioned research project had a consumption of 75 kWh/m2 [19].
Therefore, if houses shall be part of future ambitious energy strategies and be geared for a changing climate, they must include a stronger focus on electricity and the related architectural aspects: Building depths, spatial organization, daylight, natural ventilation and solar cells.

A recent publication[20] combines the above mentioned current consumptions with future climate changes. In the calculations the temperatures are set to rise (compared to 2010) with 0,5 degrees in 2020, 1,4 in 2050 and 2,7 degrees in 2085, which is in the lower end of IPCC's estimation of average global temperatures expected to rise between 1 and 6 degrees in the 21st century[21]. The calculations show that the primary energy for cooling may rise approximately 40%, while heating may drop 30%. Inside the next 25 years consumption related to cooling may exceed consumption related to heating in dwellings built according the current regulations. In a typical new office cooling may rise 40% while heating may drop 15%. All ready now, the cooling consumption is often bigger than the heat consumption.
These calculations indicate that climate scenarios should be integrated as part of the regulative and designing process to quantify the effect of cooling-reducing strategies. They also indicates that passive design strategies should be combined with active strategies to control overheating, strategies such as daylight regulation, sun shielding, controlled natural ventilation and thermal mass.
The measurements support and strengthen the conclusions regarding light buildings versus deep and darker buildings.

In a future that may seem insecure, sick and frightful, it is nice to know that good architecture is a rather recommendable remedy.

[18] Marsh, Larsen & Hacker: Bygninger Energi Klima: Mod et nyt paradigme. Statens Byggeforskningsinstitut, 2008.
[19] Marsh, Larsen, Lauring & Christensen: Arkitektur og energi. Statens Byggeforskningsinstitut, 2006.
[20] Marsh, Larsen & Hacker: Bygninger Energi Klima: Mod et nyt paradigme. Statens Byggeforskningsinstitut, 2008.
[21] IPCC: Climate Change 2007: The physical Science Basis, Summary for Policymakers. Geneva: Intergovernmental Panel on Climate Change Secretariat, 2007.