Passiv Solar design basics, a crossways for low emission buildings?

Mr. Søren Dietz - Bjerg Arkitektur

sd@bjerg.nu

Abstract. Danish Building Regulation allows a market that chooses non-compact and none-passive Solar optimized design. This leads to higher heat demand and false active solar gains to make yearly energy balance. „Soon we will have district heating with CO2 neutral biomass and batteries to save so is there a need for solar passive design"? This is a question and a way of thinking that as a passive house architect I am confronted with by politicians and architecture students. They do care about climate change, but do not seem to understand why we ought to change the way we plan building space and energy systems. The contribution architects can make to reduce climate impact by building spaces that ensure a passive exploit of the sun's energy, not just surfaces to mount active solar devices, is not commonly understood.

1. Four case studies, without and with solar compact strategy

To make my case I will present 4 case studies. A row social housing [1], a single family house[2] and two kindergartens [3,4] show how different strategies lead to different climate emissions.

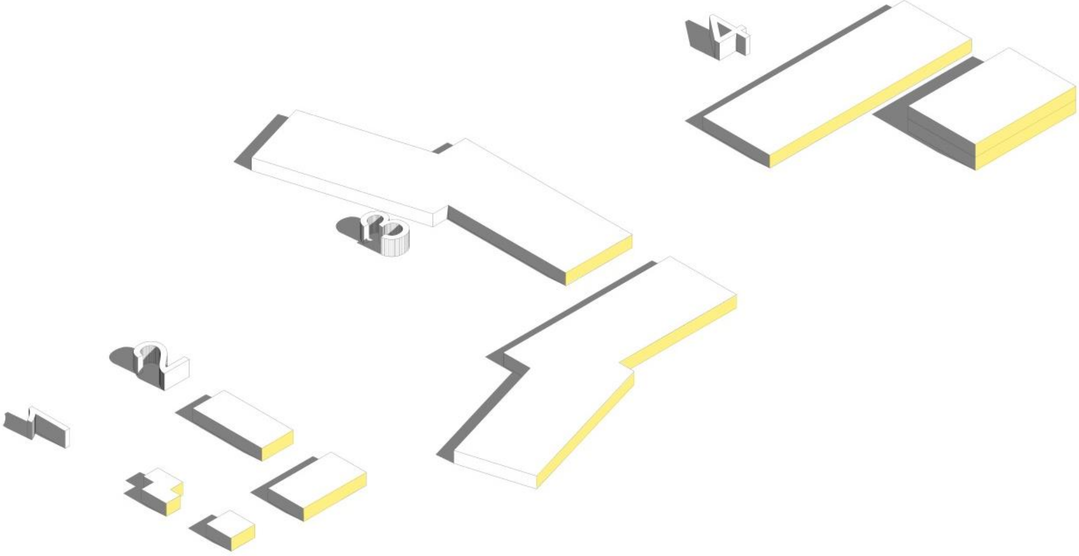

Figure 1 A schematic axonometric of the four Cases. Yellow areas are south oriented vertical elevations. The upper variants are the not solar or compact optimised versions. The lower volumes represent the same building area with an optimised south elevation and in case 1,2 and 4 a more compact building volume.

2. **Case 1, a small apartment unit of a row social housing complex.**
   The project is a competition.

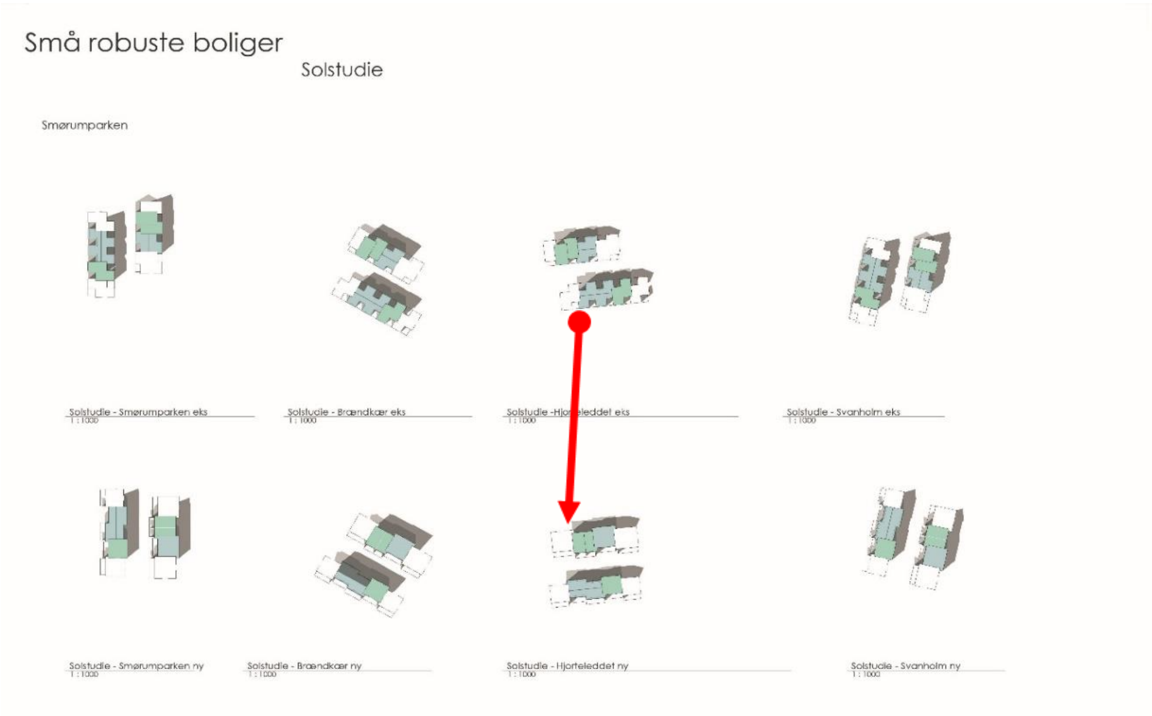

Figure 2 *Layout for the apartments was given with 4 different orientations shown on the sun/shading diagram. The upper 4 different orientations is given in the competition. The lower 4 show the shading if the apartment layout is made compact instead of the proposed shifted plan.*

One of four orientations were south oriented. Shading on this south oriented glazing is shaded because of a split layout proposal of the apartment design were half of the apartment is shifted in front to create space. This proposed split of a small south oriented apartment unit creates shading on the potential passive solar gains from the building itself and a higher heat loss surface with higher building costs as a consequence. The given layouts have shading on potential solar gains du to build landscape, orientation and the layout of the apartment itself. In this competition only the layout of the plan solution is possible to optimize. The other ¾ of the given apartment layouts without south orientation has no solar passive potential net gains due to the layout of the buildings made before the competition.

In the Danish Building regulation 2018 and 2020 regulation it is possible to calculate up to 25 kWh/m2 and year of generated energy. It is not transparent in the “Be18” calculation software whether the yearly generated active gains covers a demand.

In this analyze a PHPP calculation has been used with monthly calculated demand and generated energy. 2 different building design are compared:

- Given shifted plan (called not compact).
- Compact design proposal.
- Both of the variants are calculated with 2 different levels of active systems, 5,4 m2 solar collector, 27 m2 solar collector (full south-oriented roof area).

Solar total contribution for the not compact 27 m2 solar collector is calculated in PHPP to cover 59% of the heat and hot water energy demand. The solar total contribution of the compact design is 73%.

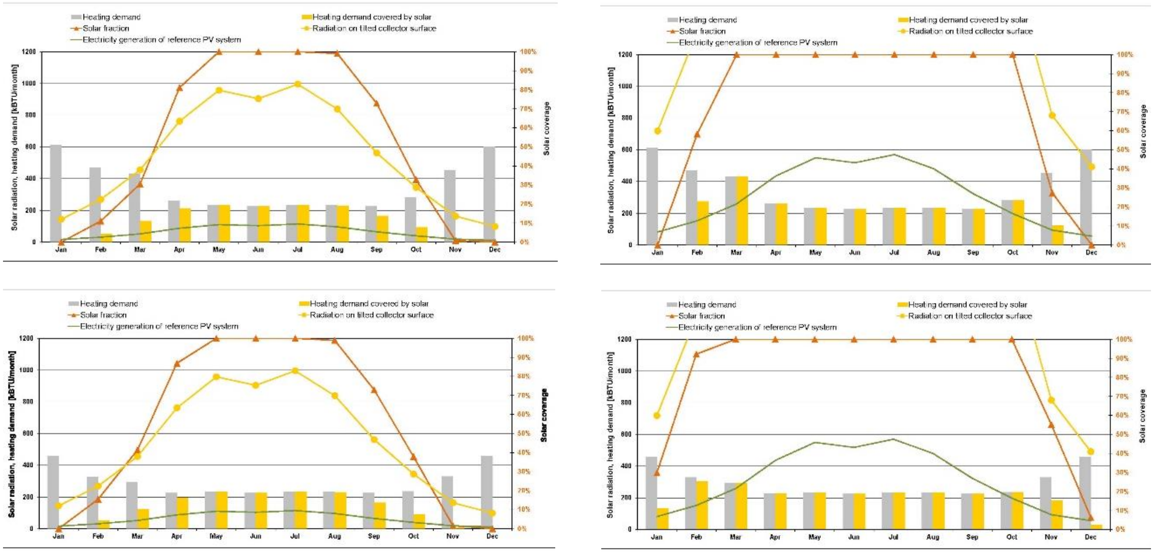

Figure 3 The upper diagrams show the shifted not compact design. On the left with 4,5 m2 solar collector and on the right with 27 solar collector. The eq. area of PV coverage is calculated and shown. On the 2 lower diagrams the compact design with results for lower heat demand and a higher monthly coverage in the winter month is shown.

If the yearly results are listed it become clear that the active potential coverage is limited. The winter gab between heat demand and active generated becomes a “performance gab”. The U values of the 2 variants is the same.

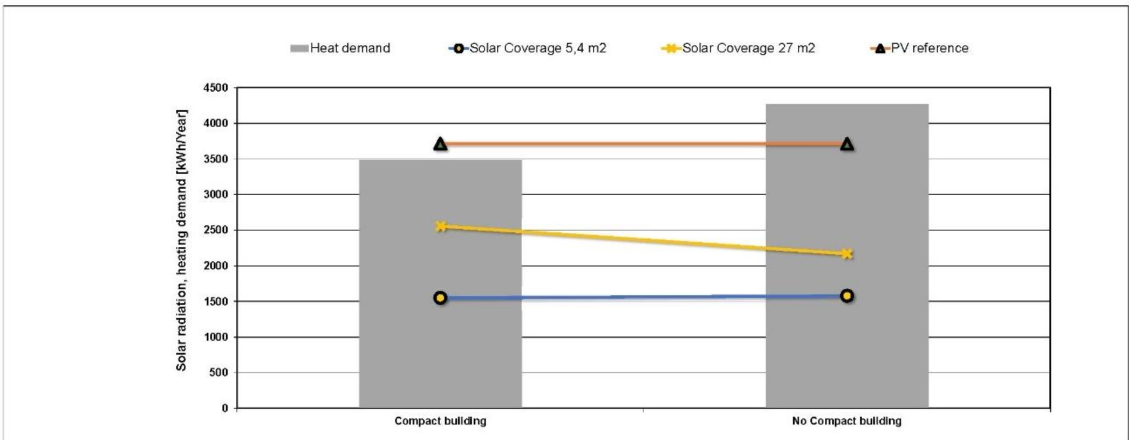

Figure 4 PHPP calculated results for a compact apartment design on the left and the proposed shifted layout of the competition project on the right. The resulting higher total energy demand is not made up for by a full roof solar collector. The winter demand cannot be covered. The compact design allows a higher coverage of the hot water energy demand and in total this results in a smaller winter gab performance.

3. Case 2, a single family house.

The second case to be analyzed is a design proposal for a south oriented villa. The Client came with a reference plan – a prefabricated standard house.

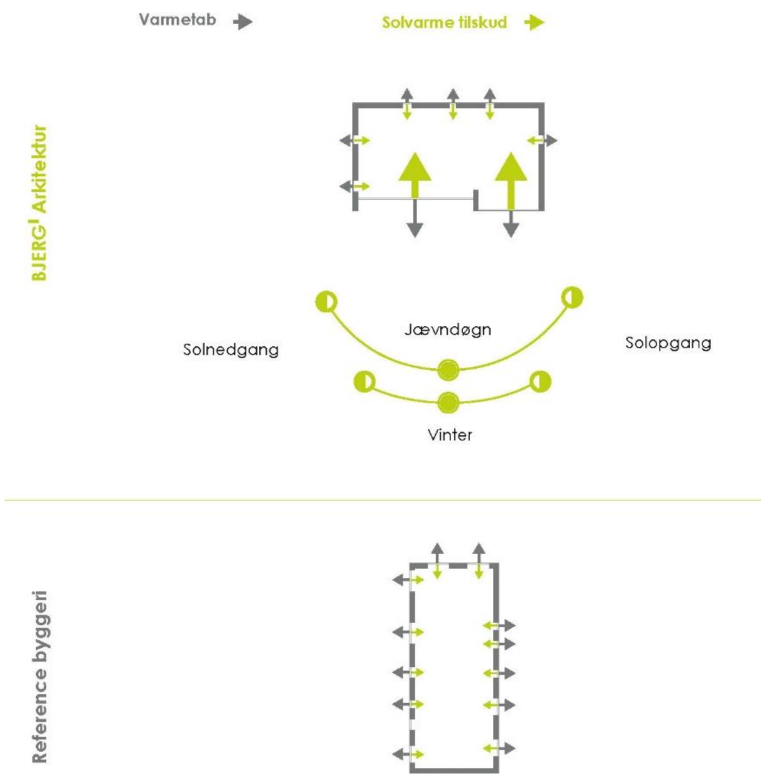

Figure 5 The upper diagram show the solar design concept, the lower plan is the prefabricated plan with mainly east- and west oriented glazing. In the middle the horizontal solar angel is shown for the 3 winter months and the winter year half. As a solar angle of more than 60 degree to the glazing reflects the solar heat away on the glazing – it becomes clear why south oriented glazing has a high potential gain and other orientations results in net potential solar passive losses.

In this case the total economy for the client is important. A prefabricated design with solar net losses is analyzed and compared with a design for the site that has a high solar net gain – but also higher costs due to the better u values and architect passive house design fee. U value prefab Wall is 0,22 W/m²K, U value PH is 0,08 W/m²K, so 36 % lower transmissions losses from the wall.

The question is now how the performance of a standard prefabricated housing is compared with a solar design optimized for the site, when the higher costs for insulation and design are considered? Now the standard prefabricated House with a higher heat load is connected to the district heating. To compare the 2 houses also the PH solar house design is calculated with district heating.

The total energy demand and costs is depending not only of the basic design but also on the energy costs. The future energy costs will in the future be depending on the greenhouse emission. Until now the structure of the CO_2 tax favors district heating. Electricity that could be used for heat pumps has a 4,5 higher CO2 tax than heat produced by fossil energy.

District heating plays a central role in the Danish energy strategy to reach 2050 low emission society. There are discussions how this is going to be implemented. “Klima rådet” [§]propose a lowering of the green CO_2 tax. In order to analyze how a CO_2 emission tax structure may influence the total costs in the future, 3 different emission tax levels are calculated.

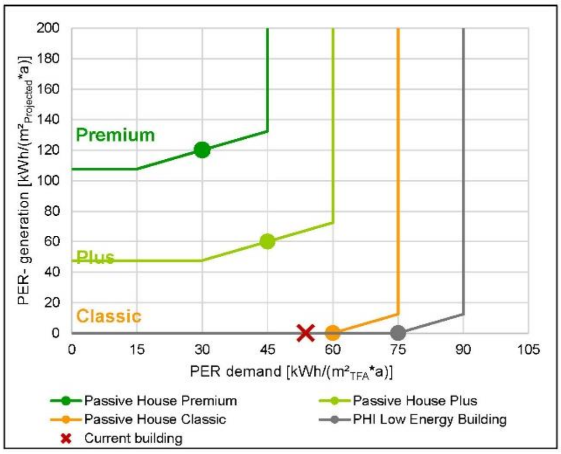

Figure 6 PH House with Compact heat

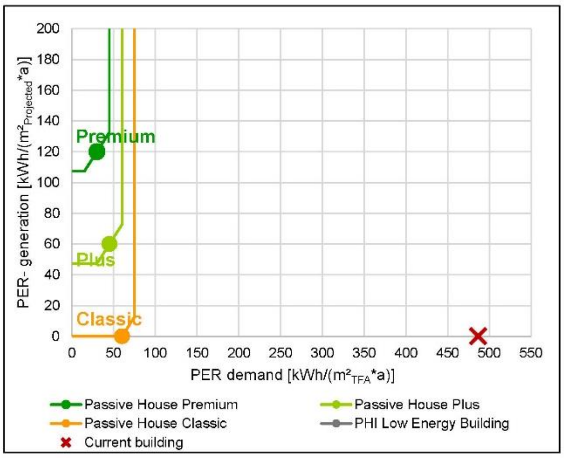

Figure 6 Standard prefab House with district heating based on hard cole

Figure 6 and 7 PHPP calculated Primary Energy Renewable demand. On the left the design for a solar south oriented passive house. On the right a standard prefab house.

Space Heat demand of the PH house was calculated to be 14 kWh/m2 and year. Space heat of the standard prefab house was calculated to be 78 kWh/m2 and year, more than 5,5 times higher than the passive house. A calculation of the total primary energy with PHPP calculated primary energy factors leads to ewenb higher difference between a PH house concept and a standard prefab house concept based on standard district heating. As mentioned before the future factor for district heating in the 2020 regulation is 0,6. The PHPP calculate a mix of energy for district heating depending on the district plant and the resources used to produce heat. The factor calculated for a big power/district heat plant using hard cole is calculated to be 4,35 or more than 7 times higher than the primary factor used in the Danish regulation. The primary energy factor for electricity in PHPP is 1,3. The energy factor for a compact heat pump/ventilation system using electricity results in a PER energy demand for the PH house of 53,7 $kWh/_{TFA}m^2$ and year. The PER result for the standard prefab house is 486,4 $kWh/_{TFA}m^2$ and year, a factor 9 lower PER energy demand for the passive house with Compact heat pump!

A significant difference in heat demand leads to a similar difference in heat load. High heat demand and heat load limits choices of heating systems based on heat pump. This can result in big differences of CO_2 emissions. The emissions for all heating, cooling, hot water and lighting energy is calculated to be 5,10 tons pr. year in the standard house and 2,69 tons pr. year in the passive house. If the passive house is equipped with a 10 m2 solar thermal collector and 38 PV panel (62 m_2) the passive house becomes a PLUS house and CO_2 "active house". The passive PLUS house PER result is – 1,76 Tons per year. A PER demand of 2,22 Tons per year is made up for with the generated energy that substitute 3,98 tons of CO_2. 1,8 times more CO_2 can be taken out than used in a PH PLUS house.

To understand CO_2 emission per person we can reduce the calculated yearly emission with the 2,7 eq. number of persons calculated in the PHPP. This leads to a calculated CO_2 per person results, which can be compared to the approx. sustainable CO_2 emission for buildings.

Emissions tons $CO_{2eq.}$ per person$_{eq}$ per year.

Standard prefab house	**PH Classic house**	**PH PLUS house**	**Sustainable limit max.** [1]
District heat (hard cole Heat(Power plant)	Compact Heat pump/Ventilation system	Compact Heat pump/Ventilation system 10 m2 solar collector 62 m2 PV collector	
		0,8	
		Generated energy -1,5	
		Emission balance: ___	
1,9	1,0	-0,7	$\leq$ 0,8

Table 1 PHPP calculated CO_2 emissions divided with number of persons$_{eq}$ living in the house. Results are compared with the sustainable max.CO_2 per person pr. year.

When the plus energy is calculated and related to the energy balance, it is important to analyze the "winter gap" situation. Energy demand that lead to emission consists of space heating, hot water and lighting energy demand.

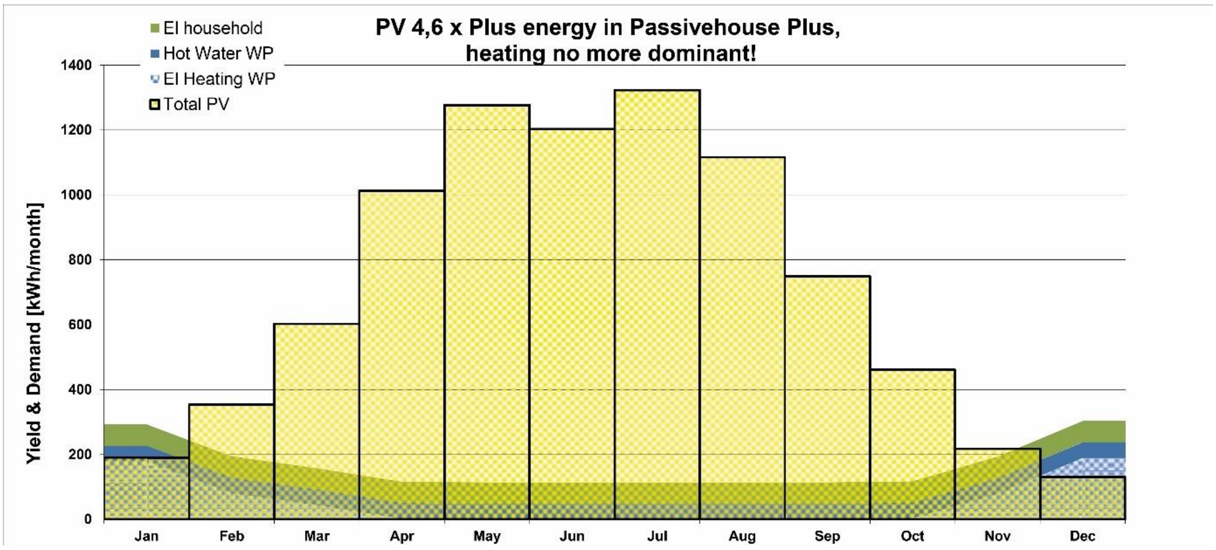

Figure 8 Monthly results for energy demand and generated energy of a PH PLUS house show that heating demand is no more dominant as the energy generated covers the electric energy demand for heating almost completely. To cover the electric energy demand in the winter months a plus in the electric energy balance of a factor 4,6 is the result.

[1] Approx. 40% of energy and resources are related to buildings. The sustainable CO_2 emissions per person is 2 Tons per year in total for all emissions related to living. 40% or 0,8 Tons of the 2 Tons per year is therefore a sustainable max. emission CO_2eq. per person per year.

This passive plus house strategy is a 4,6 times "plus house", but not what the client is asking for. Total economy of the reference standard prefab house and a passive house classic is compared. Costs are calculated in 30 years as middle costs pr. year for construction and energy.

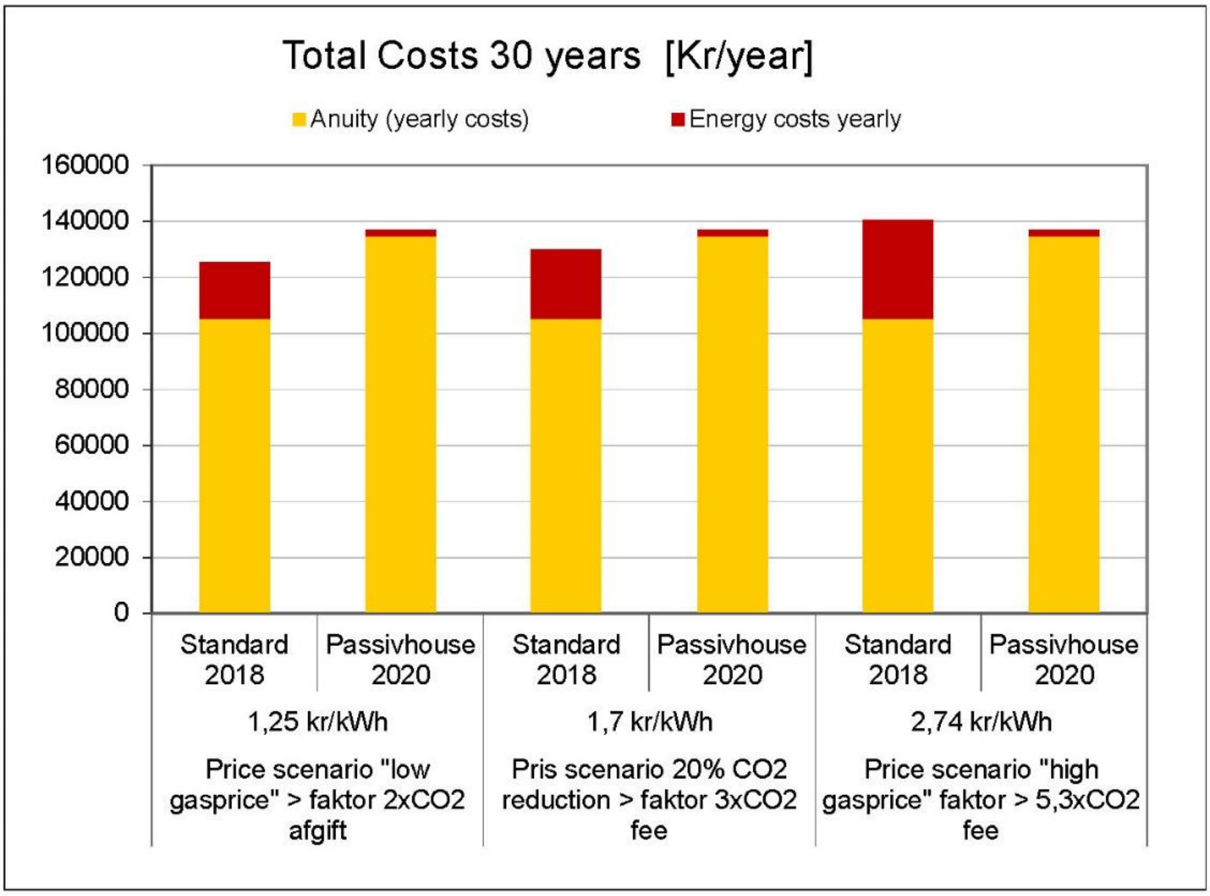

Figure 9 Result of yearly costs for 3 different energy price scenarios. With the 2 low cost scenarios the total cost for construction and energy is lower for the standard prefab house using district heating. A price scenario with a sustainable CO_2 tax results in a better total economy for the PH energy standard.

When the total costs are calculated for 30 years, investments with short life are favored. Long life investments with a sustainable long life perspective are not taken in to the result. If the client after some years chooses to sell the house, the value of the house is calculated with any long life investments. The "rest value" of the investment costs, that is the investment costs with longer than 30 years lifetime results in a value that can be put on the market and sold. The market "rest-value" of the long term investments is approx. 25% more than the standard house.

Figure 10 The "Rest-value" of long term sustainable investments. The result show that if calculated and shown – it can be a needed result to show to the bank. Often the bank makes the limit for the client – and this limit leads to investments in standard housing with lower energy related investments, short life time and potential high CO_2 emissions as shown above.

4. Case study number 3, a kindergarden competition with 1 level, east-west orientation.

Early design decisions normally include form and orientation of glazing. Sometimes form decisions is limited when a competition define a building plot or limit the number of building levels to one. In this case a kindergarden competition with one level and mainly east and west orientation of the vertical surfaces is given.

On the plot it was not possible to obtain south orientation of the main rooms for the children. The south oriented variant explore the potential of changing the site but keeping the building plan – so that south orientation would be possible. Results of PHPP calculated final energy demand show that the same building turned 90 degree has a 14,7 % lower energy demand. South orientation of the vertical surfaces is critical if the building volume is limited to one level so that compact design is limited.

A higher potential higher solar passive gain with a resulting lower final energy demand is not possible in the given competition used as case, as the plot is east-west oriented. 15% CO_2 emissions could be avoided if more vertical surfaces with south oriented glazing were possible.

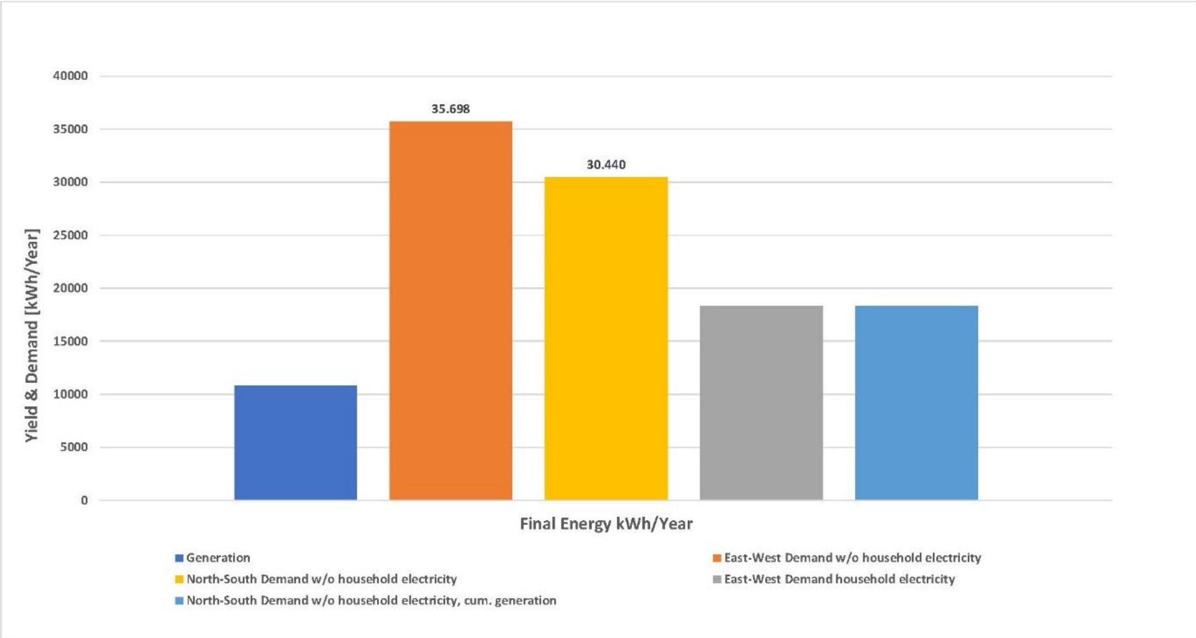

Figure 11 Case 3 PHPP results for 2 different building orientations of a kindergarden in one level. The glazing design is not optimized, only the orientation is changed. Higher passiv solar gains result in a 15% lower energy demand. Energy generated by roof PV panels is the same in both variants as the panels are south oriented in both variants.

5. Case 4 is also a Kindergarden competition.

In this case it was possible to make a compact south oriented building volume on the site in one level. The optimized variant is the same proportions but in 2 levels – so a reduction of roof and floor to ground by 50%.

Results of energy demand show a 15,9% lower energy demand if the kindergarden were in 2 levels instead of one level. The same glazing area were calculated. The difference calculated is a 50% reduction of floor to ground and roof surfaces. The cost reduction of the 50% reduced roof area and ground floor cannot be calculated fully as extra costs for the 1 level floor has to be considered. But It can be estimated that also a potential considerable investment cost could be reached if a kindergarden design were possible in 2 levels.

Emissions from a south oriented plot but limited to one level results in 16% higher final energy demand and emissions.

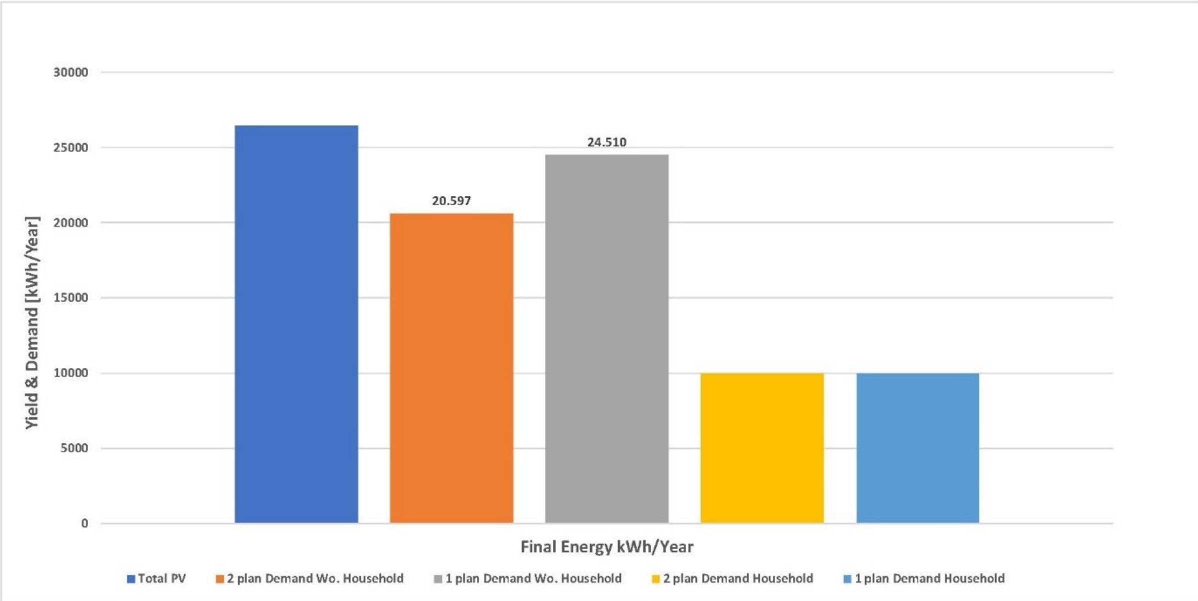

Figure 12 PHPP calculated results for 2 variants of case 4, a south oriented kindergarden competition in 1 level and a compact variant in 2 levels. Yearly final energy demand and generated energy yield of PV panels on the roof. The generated energy on the roof is higher than the energy demand.

It can be argued that a design with a big roof surface can be used for active energy elements to generate energy and in this way "balance" the energy design. A compact variant result in a smaller roof area. To analyze how active generated energy can balance the energy demand and what the effect might be to the resulting energy balance, a monthly yield and demand balance is calculated in PHPP of the 2 design variant in case 4.

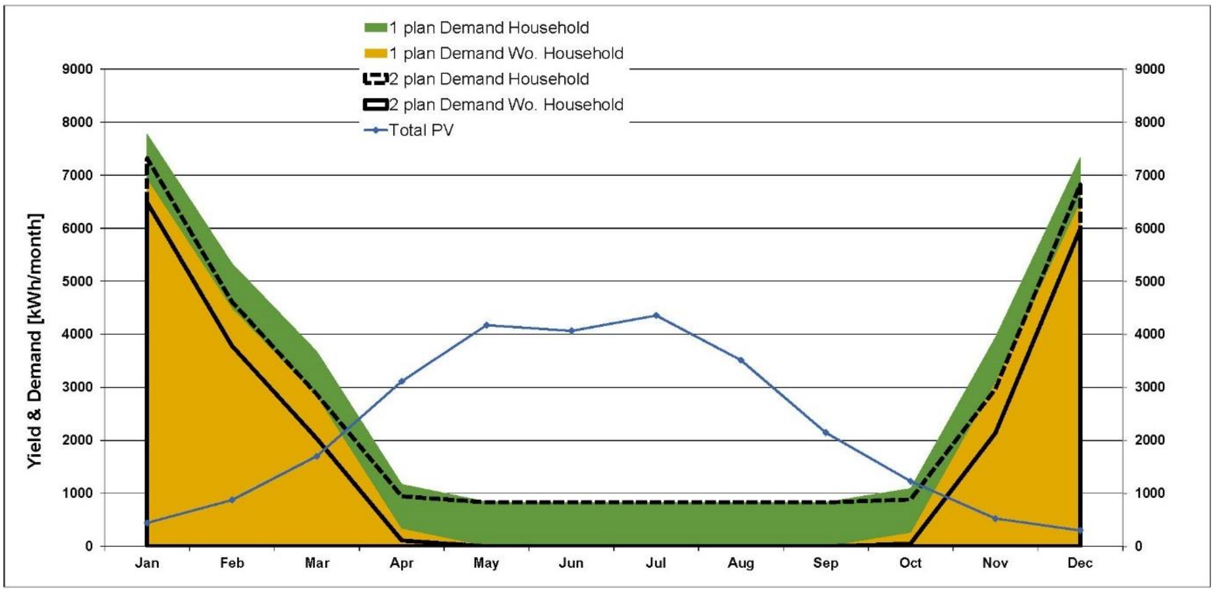

Figure 13 Monthly results of generated energy and energy demand. The energy generated from mid March to November balance the energy demand for heating and hot water of the compact 2 level design. The balance period is a little shorter when the building is in one level, resulting in a higher emission. A bigger area would mainly increase the summer peak, potential resulting in more unused generated energy.

6. Results

The 4 different cases analyzed here are all real cases. The potential variants are not real possible cases – they were not possible due to the given conditions of the competitions. In order to illustrate what the potential savings are, this paper analyzes what the results could have been – if the competition had not limited the potential savings. In other words the results show how big the impact can be on the climate emission if initial primary design is limited. Often orientation and compact design does not result in higher costs. On the contrary – higher solar passive gains results in lower heat demand and lower climate emission. Approx. 15 % reduction can be expected if the design can be made solar passive optimized show results in case 3. The same reduction again can be reach if the design is not only solar passive but also compact in shape, shows results in case 4.

Case 1 and 2 analyze layout impact on climate emissions in smaller building volumes like social housing and standard houses. Layout without optimal solar passive gains and energy "performance gab", can result in higher climate emissions that could have been avoided with no extra costs or even cost savings.

7. Discussion

The cases chosen show a variation in building volume, compact form, solar orientation and function. They are all new projects done by the office in the last year, the energy saving design of the office has been to meet Passive House standard[2] The illustrations shown of Case 2, social housing and Case 3, Single family are shown with different graphic to show how the office communicate solar orientation and shading affects to different clients. It has not been the intention to set this analysis into a specific scientific context frame. It is rather hoped that a "bottom up" approach, analyzing relevant cases of energy saving building designs and discussing its results and possible effects on energy supply, may inspire and assist politicians and decision makers working to fulfill future nZEB buildings.

It has been shown that Passive Houses as a building standard is relevant to implement nZEB energy efficient building standard.[3]

It has been shown that also Passive House buildings, when the primary design optimum is possible, does not lead to higher costs [4,5]

It also has been shown that not effective building plans can potentially result in approx. 4 times higher building costs than an optimized passive house design.[6] It is also necessary to consider and illustrate how given building sites and project guidelines can limit an optimized passive house design.

References

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2 PassivHouse definitions:
https://passiv.de/de/02_informationen/02_qualitaetsanforderungen/02_qualitaetsanforderungen.htm

3 The Passiv House standard and its relevance for the implementing nZEB and the Global UN framework for energy efficient buildings. Colclough et all., Passivhouse procedings 2018, P 215.

4 Passivhaus Schulprojekt – Kostenredduzierung durch passivhausstandard – Betriebserfahrungen und weitere Optimierungsansatze, Bodem et all Passivhouse procedings 2018, P 259.

5 Integrationskindertagesstatte "Wichtel" in Lubbenau/Spreewald, Rentzsch, Passivhouse procedings 2018, P 309.

6 Passivhaus – Quo vadis?, Burkhard, Passivhouse procedings 2018, P 423

1 Energi- Forsynings- og Klimaudvalget 2017-18 EFK Alm.del Bilag 214,https://www.ft.dk/samling/20171/almdel/EFK/bilag/214/1882023.pdf
PassivHouse definitions:
https://passiv.de/de/02_informationen/02_qualitaetsanforderungen/02_qualitaetsanforderungen.htm