Overheating and insufficient heating problems in low energy houses up to now call for improvements in future

Requirements for improved energy performance have shifted major focus on energy calculations in the design process. Experience from a Danish research project on low energy homes built today, shows that more attention has to be paid on indoor climate and specially temperature control issues to ensure comfortable living conditions in future houses.

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Energy savings in the residential area are essential in order to achieve the overall goal for energy savings outlined in the 2008 Danish energy political agreement. The residential area is responsible for approx. 30% of the combined energy consumption in Denmark, and, therefore, holds great potential. In recent years, this has resulted in several experimental buildings and development projects with focus on developing low energy houses in a Danish context.

Unfortunately, not all experiences from these low energy houses have given positive feedback, and problems with indoor climate in the houses, have been in focus. However, it is important to point out that some of the problems with low energy houses also existed in previous constructions. For instance, the problem with overheating is well-known, but the problem is more distinct with low energy houses as the houses heat up very quickly, so even though many details and good solutions in the houses have been considered, problems can still arise. The objective of the work is to analyze these problems and evaluate how the problems can be removed in the future or be heavily reduced in future houses in order to ensure that future low energy houses in Denmark will be healthy houses with good indoor climate.

Keep the sun outside!

Previous experience from houses built as low energy constructions has shown that very high temperatures and consequent discomfort arises quickly in some houses. The high temperatures occur partly due to the several south facing window sections, which in many cases are poorly shaded from solar radiation, and partly due to lack of ventilation or free cooling options.

An analysis of the problems with overheating shows that implementing the option of active use of window airing in our houses combined with external solar shading is essential in the future. It is of great importance, that the solar shading is chosen as an external solution, since this type of shading is the most effective solution. Many technical solutions are available. **Figure 1** shows four different solutions. Illustration a. shows an automated solution where blinds run up behind the facade cladding when not in use. In the illustrations b. and c. solutions with fixed overhangs above the windows are shown. In such cases it is essential to make a careful calculation, that happens when the sun drops below the shading device causing direct radiation into the house. In Illustration c. louvers fixed on rails are

a. **b.** **c.** **d.**

Figure 1. Examples of external solar shading.

seen. These can manually be run in front of the windows when needed. At the house in Illustration d. it is planned to grow deciduous vegetation (not yet planted in this photo) over the rooftop, which, during the summer will provide shade on the windows around the terrace, but during the winter will allow the sun to come into the house.

Combined with solar shading, active use of window airing/night ventilative cooling will help cool down the house. During the day, when the house is empty or at night, it should be possible to ventilate and utilize free cooling effect that can simply be provided by opening windows. In order to make this possible, the openings in the house must be incorporated during the beginning of the design phase, so that the house is designed with the possibility of ventilative cooling, since it can be difficult to create this option after the house has been built.

Another question is the utilization of thermal mass, i.e. could heavy materials affect the indoor temperatures in the house in either a positive or negative manner. The conclusion is that the thermal mass only has a positive effect as long as it is possible to cool down the construction during the night, i.e. the use of thermal mass only works when it is possible to provide a suitable air change during the night. If this is not attained, the thermal mass can even enhance the problems with overheating in the house instead.

Control of the indoor temperature during summer

During the design process the main attention is drawn to the expected energy consumption of the house. This often includes large window areas in the southern room in order to increase the solar gain, and thereby reduce the heating need. The thermal conditions in these southern rooms often become critical, due to focusing only on energy needs. In order to avoid this, the temperatures in such critical south facing rooms need to be analyzed in order to determine whether the rooms have a risk of too high temperatures.

Today, the energy demand is calculated in Denmark with Be10 program, which is a simple energy calculation program, based on the single zone monthly calculation. The program has a very simple control of the indoor climate in the form of a built-in "over temperature penalty", but this is a very uncertain control since the program treats the building as a single zone and will, thereby, often not reveal problems in e.g. south facing rooms with large amounts of solar radiation. Here the problems typically occur, when the occupants have closed the doors to the northern part of the house and thereby reduced the volume. It is important to understand that the indoor climate cannot be controlled by an energy calculation program, but must be analyzed with tools suited for indoor climate.

One way to control indoor climate could be via a simple calculation of the daily average and maximum temperature on a summer day. Calculation can be done in app. one hour, as many of the necessary parameters already are defined in connection to the energy calculation (window sizes, solar shading, U-values). To illustrate how this is done, a calculation of the daily average and maximum temperatures are made for a south-facing room, where, in two successive summers, very high temperatures in the finished house were recorded. Measurements from the living room are shown in **Figure 2**.

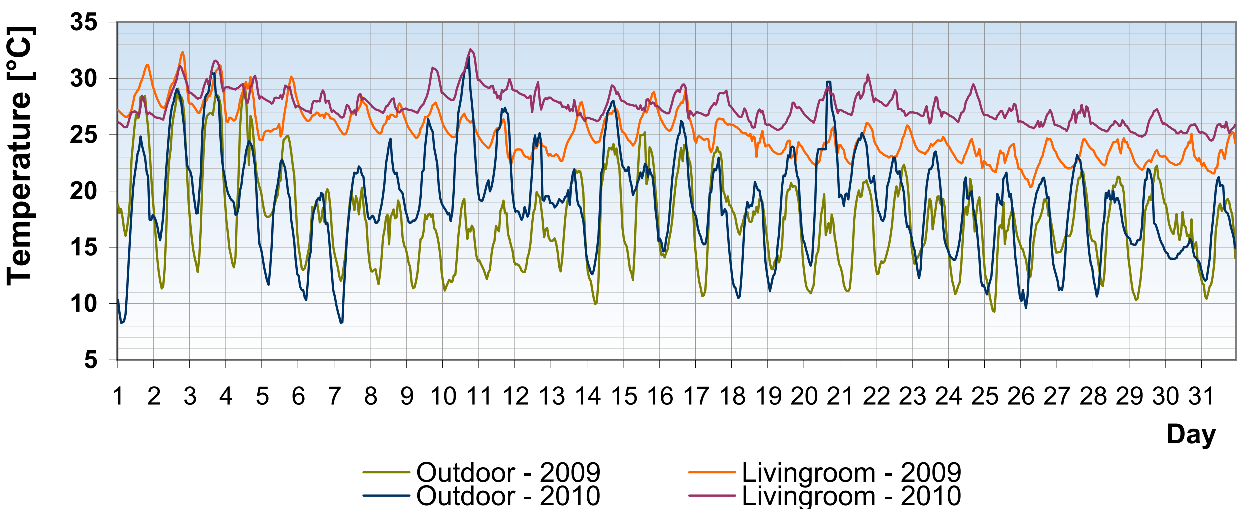

Figure 2. Outdoor temperatures and room temperatures measured i July 2009 and 2010. (Results from the white one-storey house in Skibet.)

In the method, calculations have been made both for an occupied house (L1) and an empty house (L2). Also the ventilation rates are varied. (V1) is calculated for the ventilation rate specified in the energy calculations. (V2) are made for increased use of window airing. All calculations are done with weather data for June. The results of calculation shown in **Table 1**.

Table 1. Results for the daily average temperature and the daily maximum temperature in July.

	Case A	Case B	Case C	Case D
Person load + lighting	L1	L1	L2	L2
Natural ventilation	V1	V2	V1	V2
Daily average temperature	35.4°C	30.4°C	34.5°C	29.8°C
Daily maximum temperature	38.6°C	33.8°C	37.6°C	33.1°C

From the table it is seen that in all cases temperatures reached well above comfort temperature. This calculation indicates that the house will have problems with overheating in the summer, just as it was found from the measurements in the house. Increased solar shading, reduction in window area or more ventilative cooling could have been the solution to the problems, but unfortunately the temperatures were not checked during the design process for this house and therefore the problems were not shown before the occupants moved in.

Insufficient heating during winter

In low energy houses, it is quite often very small amounts of energy that has to be added to the house in order to heat it up during winter. If the heat outputs are sized so that internal heat gains are considered to be always present and the average heat loss per floor area instead of room specific losses are used, the house will easily experience situations with insufficient capacity in the building as soon as the present conditions in the house deviate from the calculation prerequisites. For example, it happens in situations where the outdoor temperature is lower than -12°C (Danish design value) and you want to keep the room temperature higher than 20°C, or if the house is not as airtight as assumed in the calculations. It is therefore recommended to use careful room by room sizing with full heat losses and some capacity margin in order to avoid this situation.

Another issue that needs to be highlighted is the reduced or missing option of using individual control of the room temperature in the air heating systems used. While typically under floor heating was used in wet rooms, other rooms were equipped with centrally controlled ventilation air heating, where supply air was distributed both from floor or ceiling level and no recirculation air was used. Such ventilation air heating can, among other things, result in cold corner rooms in a house, an example is shown in **Figure 3**. Insufficient heating in some rooms with simultaneous overheating in some other rooms was also reported by Minergie® Agentur Bau in their study for houses with ventilation air heating. They concluded that the disadvantages with this type of air heating are too great compared to the

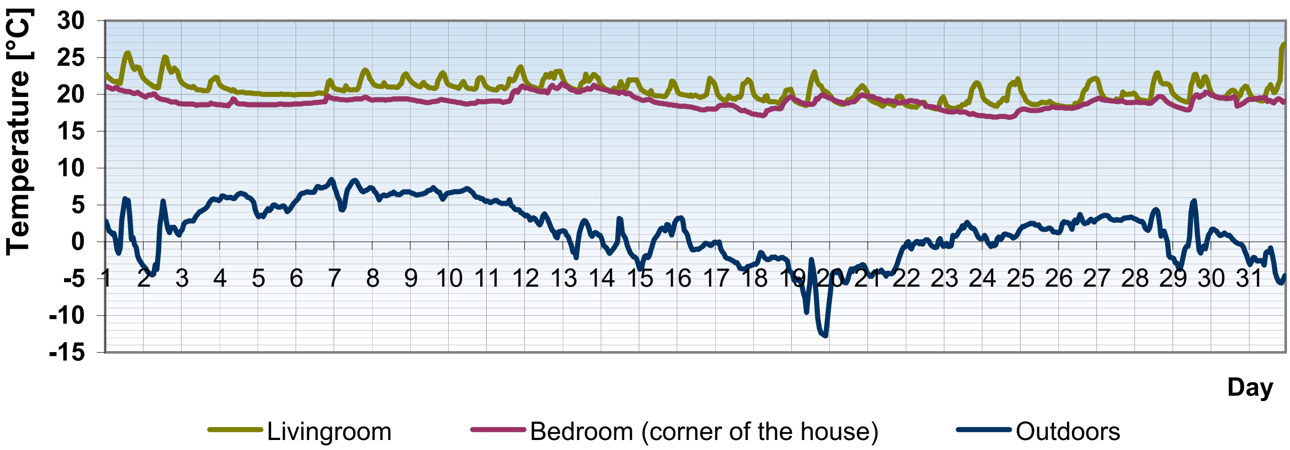

Figure 3. Outdoor temperatures and room temperatures measured in December 2009. (Results from the white one-storey house in Skibet.)

savings achievable by not using a hydronic distribution system [Minergie® Agentur Bau, 2007]. If the house has a poor distribution of heat between rooms (e.g. due to soundproofing in walls between each room), an individually controlled heat supply in each room would be able to increase the temperature in the room if so required as long as the capacity is available in the system. The problem with the uneven heat distribution between the rooms also underlines the necessity of calculating several temperature zones of the house where heat loss and heat supply are different from zone to zone.

Finally, it is to be pointed out that the air tightness is an essential parameter when sizing heat outputs and calculating energy use, which is illustrated in **Figure 4**. If the construction is leaky, the infiltration will cause infiltration, which has to be heated. If heat outputs have been sized with a small or no safety margin already, an increased infiltration will quickly result in heating problems.

Demand controlled ventilation

Indications show that future houses will be larger and larger and at the same time we will be fewer people in the houses. This means that we will have a greater amount of m² per. person, which also leads to a reduction in the need for fresh air per m² of the house – at least when the temperature, CO_2 and relative humidity are evaluated. Whether or not the same applies to other parameters such as radon and formaldehyde is not evaluated in this analysis, but must be concluded before a final appraisal of the demand controlled ventilation in houses can be completed.

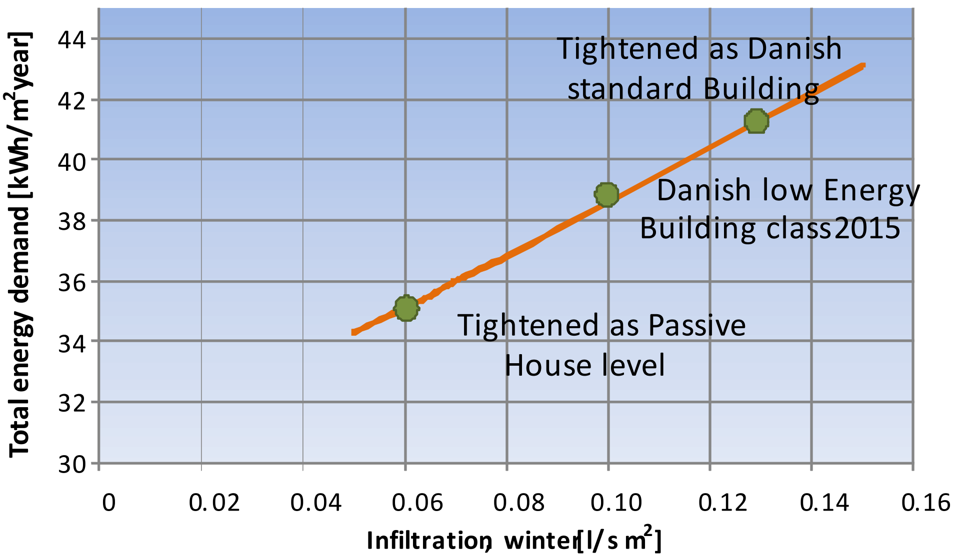

Figure 4. Energy use for heating, domestic hot water, fans and pumps as a function of infiltration – a case study.

Different solutions for demand controlled ventilation are today available at the market. Most of the systems are operated automatically via measurements of relative humidity (RH) but some solutions also include RH combined with measurements of CO_2-levels. These solutions ensure a robust ventilation method in the house where fluctuation on the internal loads is taken into account, but the solution with measurement of both RH and CO_2 will provide the most reliable solution. However, CO_2 with an air change of 0.5 h^{-1} will often only be a problem in short periods with guests in the house, but if air change rates of less than 0.5 h^{-1} are allowed in the future, it is debatable whether or not the additional investment is necessary as the analyses in the project do not show any problems with high RH but rather the opposite. It is, however, important to point out that small rooms with high, internal loads must have higher air change rates. These are typically bedrooms and children's rooms where there is internal load all night. The children's rooms are in some cases extra critical as there is also activity during the day in these rooms and pollution added to the room air from many plastic toys etc.

Another important parameter is evaluation of the energy efficiency in the ventilation systems, i.e. the SFP value. There is a large fluctuation in the SFP value despite the fact that all of the investigated systems have been installed within the last 2-3 years. A high SFP value can ruin even the best of intentions of creating an effective and energy-friendly ventilation system, so it is, therefore, important that the SFP value as a standard procedure is documented at the delivery of the construction based on measurements of the installed system.

Using previous experiences - and build on them

To ensure a healthy and comfortable environment in future low-energy housing we must make demands for the indoor environment in our homes on an equal basis with demands for the energy use. At the same time the engineer and architect needs to be better at working together from project start so that the architecture is optimized for the requirements for low energy, which will be

- a passive house of 141/169 (net/gross) m² from the Comfort House project in Skibet near Vejle, Denmark
- heat source: ground source heat pump combined with air/water heat pump
- heating system: underfloor heating in bathrooms and ventilation air heating in other rooms
- ventilation: heat recovery mechanical supply and exhaust ventilation, demand controlled (RH)
- U-value of ext walls 0.085 W/(m²K) and windows 0.66 W/(m²K)
- fixed solar shading on southern and partly eastern and western windows

- a passive house of 154/198 (net/gross) m² from the Comfort House project in Skibet near Vejle, Denmark
- heat source: ground source heat pump combined with air/water heat pump
- heating system: underfloor heating in bathrooms and ventilation air heating in other rooms
- ventilation: heat recovery mechanical supply and exhaust ventilation, demand controlled (RH)
- U-value of ext walls 0.087 W/(m²K) and windows 1.02 W/(m²K)

- a house build in 1974 renovated in 2010 to low energy class 1 (energy for heating, hot water and building electricity app 40 kWh/(m²-gross a)). 176 m² from Tilst near Aarhus, Denmark
- heat source: low temperature district heating
- heating system: underfloor heating and radiators
- ventilation: heat recovery mechanical supply and exhaust ventilation, demand controlled (RH and CO_2)
- U-value of ext walls 0.12 W/(m²K) and windows 0.96 W/(m²K)
- combined use of mechanical ventilation during the winter and natural ventilation during the summer.

found in optimized shape of the building, integrated solar protection, proper orientation, use of passive measures, etc.

Furthermore, it is important to involve the experiences already available from the low-energy buildings that are built today. It requires that we become better at sharing both the good experiences, but also the bad experiences we've already got. One can learn a lot by making mistakes and it is therefore important that errors are not hidden away, but used to improve the buildings ahead.

References

Minergie® Agentur Bau, Position des verieins minergie ® zum thema luftheizung, Notat, 11.10.2007.

SBI-anvisning 202, Naturlig ventilation i erhvervsbygninger, Karl Terpager Andersen, Per Heiselberg and Søren Aggerholm, Danish building research institute, 2002 (in Danish).

Vurdering af indeklimaet i hidtidigt lavenergibyggeri - med henblik på forbedringer i fremtidens lavenergibyggeri. T.S. Larsen, Department of Civil Engineering, Aalborg University, 2011. 65 p. (carried out for the Danish Enterprise and Construction Authority, DCE Contract Reports; 100). (in Danish).