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Energy Consumption and Indoor Climate Measurements in New Low-Energy Houses

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Abstract

The CLASS1 project commenced in 2007 and involves 5 countries: Denmark, Estonia, France, Italy and Romania. Originally, 442 dwellings, a kindergarten and an activity centre for elderly people were to be designed and constructed as "low-energy class 1" houses according to requirements set by the Municipality of Egedal/Denmark, for the CONCERTO community. This means that the energy consumption is 50% below the energy requirements set by the Danish Building Regulation of 2008 (reference). 65 apartments and about 50 single-family houses were constructed. Due to the financial crisis, about 240 new dwellings and a CO_2-neutral district heating network will not be constructed within the timeframe of the project Therefore, a contingency plan was developed introducing the renovation of public buildings and large-scale implementation of solar cells on public buildings of the municipality.
The CLASS 1 project used the requirements to low-energy buildings as a driving force for the technological development of 6 different key building components/technologies: windows, slab and foundation insulation systems, bio-mass gasification, local district heating distribution networks, ventilation heat recovery combined with heat pumps and a Building Energy Management Systems.
The overall concept of a CONCERTO project, to combine energy efficiency with renewable energy supply, is thus reached through the combination of low-energy new buildings,the improvement of the energy efficiency of public buildings and PV systems. The paper describes the results obtained for energy and indoor environment evaluations. A cross reference exists to another paper submitted for the conference on "Occupant experiences and satisfaction with new low-energy houses".

Keywords – low-energy houses; energy consumption; indoor climate

1. Introduction

The energy demand of the area *Stenløse Syd* has been monitored since December 2009. The buildings in the investigation concern 60 single-family houses, 65 low-rise high density flats, an activity centre for elderly people, and a kindergarten.

The single-family houses were designed and constructed with a heating demand corresponding to the Danish low-energy standard referred to as "low-energy class 1". This means that the energy demand has to be 50% lower than the requirement in the Danish Building Regulations 2008 (BR08 [1]). The standard corresponds to *Low Energy Class 2015* in the present Danish Building Regulations – BR10 [2]. The single-family houses were to be heated by a heat pump supported by a 3 m² thermal solar system for heating domestic hot water. The 65 apartments were designed and constructed with an annually heating requirement of 15 kWh/m². They are to be heated by district heating.

The kindergarten and the day-care centre were also designed and constructed for *Low Energy Class 1* and heated by heat pumps with solar heating systems for hot water preparation.

All dwellings were to be equipped with a mechanical ventilation system with heat recovery and an electronic system for energy monitoring and control of the heating systems. The first houses were occupied in 2008.

2. Methods

The monitoring was made with building energy management systems (BEMS) produced by the companies, *EHK Home Automation, Seluxit and Zensehome*. The residents had a free choice of brand of system. The systems monitor the total electricity demand, electricity demand for heating and the total consumption of water. The data from the monitoring were available on an online server, from which the data were downloaded and analysed. Not all data from the mentioned period were available in all the houses due to several factors: houses were completed later, the systems were installed later or the systems did not function adequately.

The monitored data from the data loggers were modified in order to compare them more accurately with the value required in BR08. The normative requirements in BR08 for the total energy demand for dwellings prescribe the energy demand of heating, ventilation, cooling and domestic hot water (DHW) and the maximum allowed annual demand is 35 kWh/m² plus 1100 kWh divided by the heated floor area, m². The normative requirement for municipal buildings prescribes the energy demand for heating, ventilation, cooling, DHW and lighting with a maximum annual value of 50 kWh/m² plus 1100 kWh divided by the heated floor area, m².

For dwellings, the value of the monitored total electricity demand is subtracted an estimated value of the rest of the energy used for lighting and electrical devices. Statistically, this electrical demand is annually 4000 kWh for a single-family house and 2000 kWh for flats. The monitored energy demand of the heat pump included the electricity used for space heating, DHW, pumps, and fans. The requirement to the net heating demand is maximum 25 kWh/m²/year in single-family houses, thus the demand of DHW, pumps and fan was subtracted with estimated values. Finally, the resulting electricity consumption for space heating was multiplied by the COP factor of the heating pump, which was estimated to be 2.5. The energy demands were defined in kWh/m²/year.

3. Monitored Energy Demand - Flats

The 65 low-rise flats came in three sizes, 82 m², 84 m², and 110 m². In almost all the flats monitoring was on-going since July 2010. The majority of the flats, more than 80 %, had monitored data for more than two years, which gave a good basis for a reliable analysis.

An overview of the annual net space heating energy demands of the flats are shown in Figure 1. The average demand was 17 kWh/m², which was close to the requirement of 15 kWh/m²/year, cf. BR08 [1].

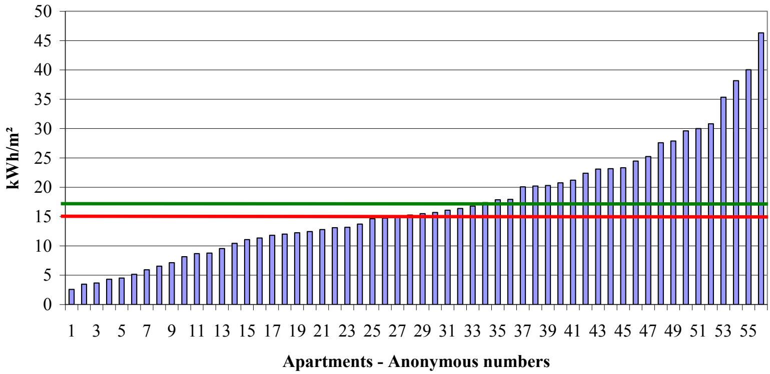

Figure 1 Annual net space heating energy demand, Red = Requirement: 15 kWh/m² year, Green = Average demand of the apartments, 17 kWh/m² year

The total electricity demand was monitored in most of the flats. It consisted of the demands of the ventilation system, for lighting and for electrical devices.

A standard electricity demand of the ventilation system was calculated from the data given on the system with an annual demand of 735-835 kWh depending on the size of the flats. This was subtracted from the total electricity demand and thus gave the demand of lighting and electrical devices. Normally, the annual electricity demand was approximately 2000 kWh per flat. The average annual demand in the flats was monitored to be 4700 kWh per flat, see Figure 2.

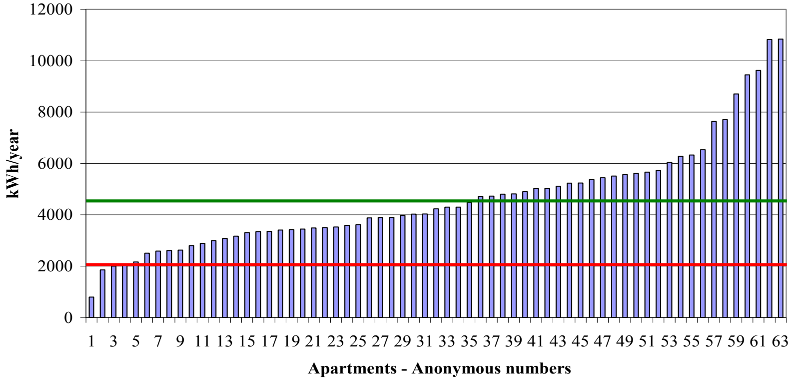

Figure 2 Annual demand of lighting and electrical devices in the flats, adjusted with a factor 2.5 for production of electricity

4. Monitored Energy Demand – Single-Family Houses

Of the 47 single-family houses built, 22 had monitored data for more than six months, and 17 houses had monitored data for more than one year. The data were adjusted as described in *Methods* and presented on Figure 3. The green marking illustrates that the value equals or is below the requirements. It appeared that most houses had higher demands than the requirements. These were, however, based on standard user behaviour according to the Danish Building Regulations of 2008 and calculated with an indoor temperature of 20 °C.

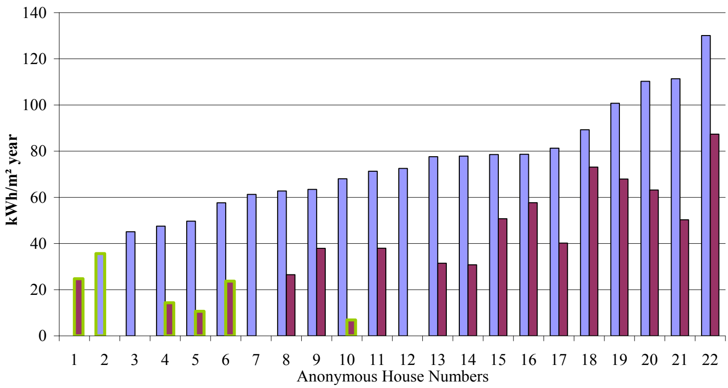

Figure 3 Electricity demand (ventilation, heating, DHW) according to BR08 low energy class 1(blue), Net Space Heating demand (red) maximum prescribed demand 25 kWh/m² year

Relations Between the Measured Indoor Climate and the Energy Demand

In the period from 16 to 23 March, measurements of the indoor climate were made in 7 single-family houses. The daily energy demand of 4 houses was monitored in this period. The houses are denoted MK7, MK26, KD7 and KD23a.

There was a tendency that the space heating decreased after a day with many hours of sun due to less need of heating, and increased after a day with no sun. The houses were all made from brickwork expect KD7 which had wood cladding. MK7, MK26 and KD7 housed two adults and two children, and KD23b housed two adults and one child.

In one example calculated and presented in Figure 4, a standard single-family house of 154 m² only complied with *Low Energy Class 1,* when the set-point for space heating was 20 °C, but exceeded the requirement when the temperature was higher – at 23 °C it increased by about 25%.

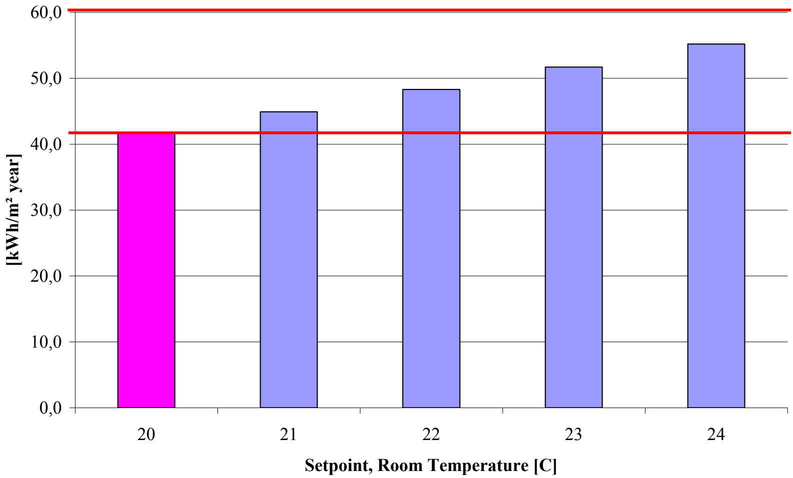

Figure 4 Total energy demand of a standard house with different setpoints of the room temperature, calculated according to the energy frame of Danish Building Regulation 2008. *Low Energy Class 1* is 42.1 W/m²K year and *Low Energy Class 2* is 60.4 W/m²K/year

One house had significant higher energy consumption in comparison with the other houses; see Figure 5, which was explained by the higher average temperature in the living room.

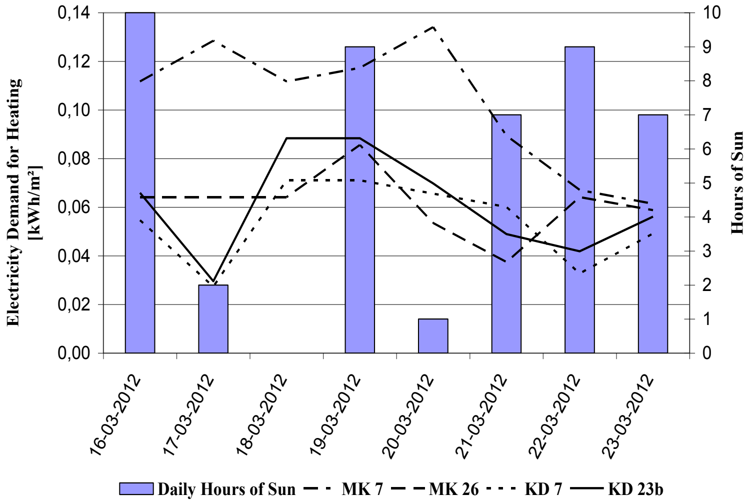

Figure 5 The eight days of measurements, the electricity demand for heating is shown againts the hours of sun for every day

Significance of the average weather data in relation to the actual

The energy demand of the building was normalised according to the actual weather conditions regarding degree days. In Figure 6, the normalised demands were compared with the pre-estimation based on average degree days.

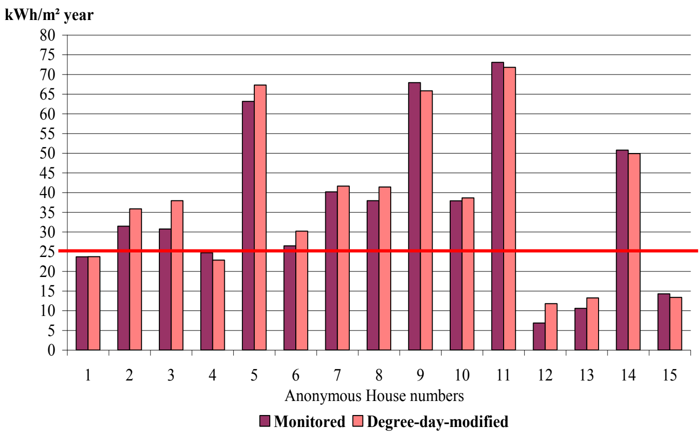

Figure 6 Net space heating demand in 15 single-family houses, actual compared with the degree day corrected

The modified data for degree days differ annually up to 7-8 kWh/m², which is a significant amount. Unexpectedly higher or lower demands in the houses could thus to some degree be explained by the weather data.

5. Indoor Climate Measurements in the Single-Family Houses

The measurements of the indoor climate were carried out in mid-March 2012 in seven single-family houses. The investigations comprise measurements of relative humidity of the room air, room air temperature, the CO_2 concentration of the room air, and the average ventilation rate in the whole house.

The average ventilation rate was measured using a passive tracer gas technique, the so-called PFT method (PFT: PerFluorocarbon Tracer). Tracer gas is emitted passively at a constant and known rate from miniature tracer gas sources and the average tracer gas concentration in the room air is determined by using passive adsorption tube samplers. The samplers are analysed in the laboratory through thermal desorption and gas chromatography.

Results

The summary of the results of the measurements is stated below. For each location in each house the Figures 7 – Figure 9 show average, minimum and maximum values of relative humidity, room air temperature and CO_2 concentration, respectively. Figure 10 shows the whole house average ventilation rate for the measured period.

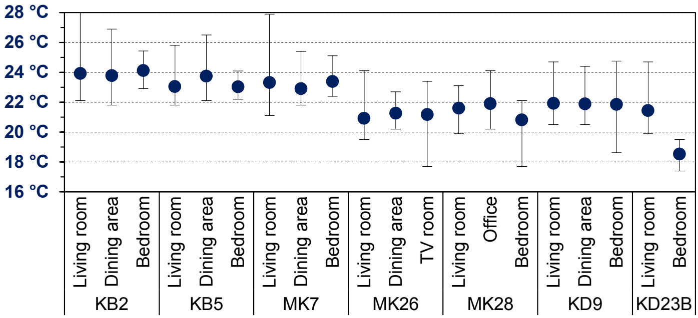

Figure 7 Room air temperature - average, minimum and maximum

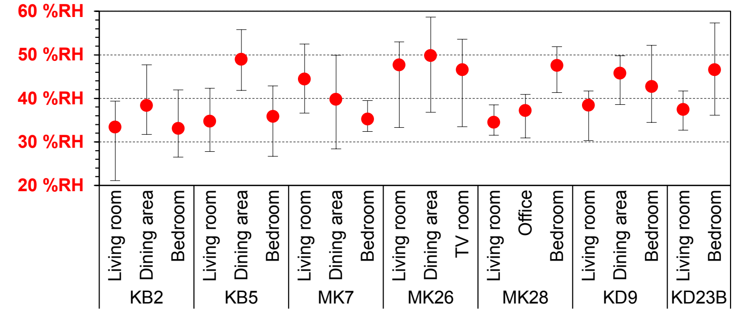

Figure 8 Relative humidity - average, minimum and maximum

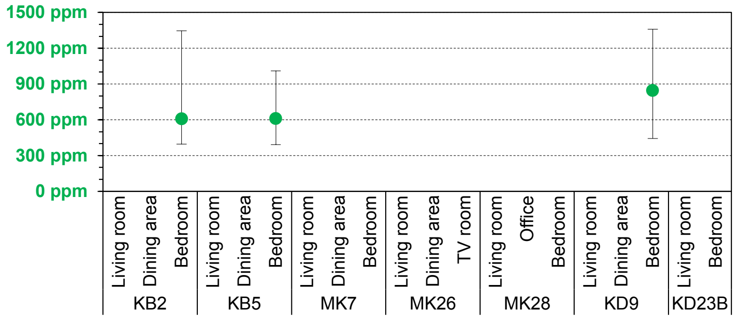

Figure 9 CO_2 concentration in bedrooms in three houses
- average, minimum and maximum

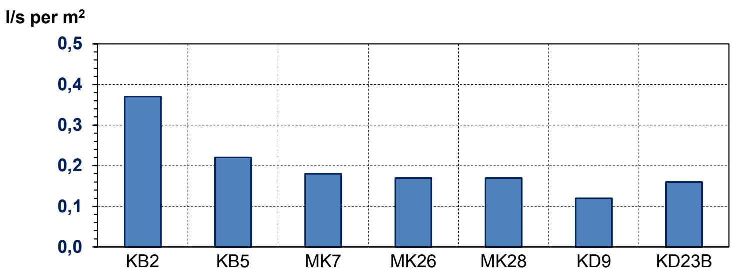

Figure 10 Whole house average ventilation rate

According to Figure 7 the highest room air temperatures were found in house KB2 and MK7 with average room air temperatures about 24 °C and peak temperatures around 28 °C.

Generally, the overall relative humidity in the investigated houses was on the low side except for house MK26 and a few isolated cases, where the relative humidity at one location (room) differed from the relative humidity at other locations in the same house. Referring to Figure 8 the isolated cases were the dining area in house KB5, the bedroom in house MK28 and the bedroom in house KD23B. As an example, Figure 11 shows how the relative humidity in the dining area in house KB5 differed from the relative humidity in the living room and in the bedroom.

In house MK26, the relative humidity in all three locations was considerably higher than in the other houses investigated. Average relative humidity for the whole house was about 48 %RH, whereas the relative humidity of the whole house in the other houses was about 40 %RH. The family in house MK26 included two small children and in the dining area clothes hung out to dry were observed.

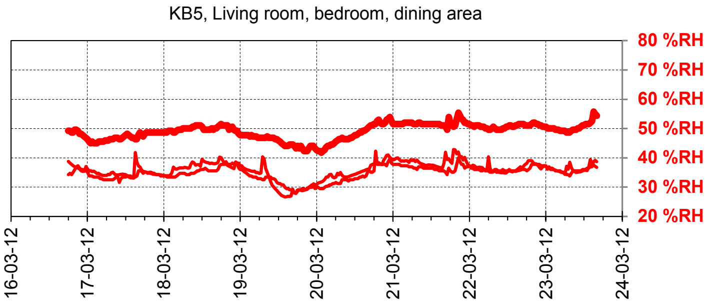

Figure 11 Relative humidity in the 3 rooms in house KB5. The upper, bold curve is the dining area

Generally, the ventilation rates were low, see Figure 10. The houses were mechanically ventilated and ventilation rates of 0.3 l/s per m^2 were the target in accordance with the Danish Building Regulations. Figure 1212 shows results from a different investigation (SBi 2011:21 in Danish) [4] carried out in newly built detached, single-family houses comparable to the investigated houses in *Stenløse Syd* with respect to ventilation. As can be seen, ventilation rates were low.

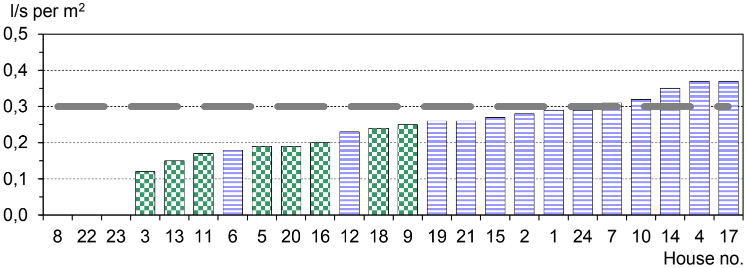

Figure 12 Results from a different investigation (SBi 2011:21 in Danish) of detached single family houses comparable to the houses in Stenlose Syd. Blue columns are mechanically ventilated houses whereas green columns are naturally ventilated houses

6. Conclusion

The monitored heating requirements complied with the design requirements in the flats, while the total energy consumption of lighting and electrical devices is more than double compared to the normal. The visibility of the energy demand given by the data logger was supposed to get the occupant to lower the demand, but that did not seem to be the case.

The electricity demands in total and for heating in the single-family house were higher than required and expected. A colder winter than normal adds extra demand for heating and a warmer summer for ventilation, but the difference according to the actual weather cannot account for this. In the indoor climate measurements, it was seen that the indoor temperature was all above 20 °C and an average of 22 – 23 °C were normal. It was shown that this gives a considerable increase in the electrical demand (for the heat pumps). Some occupants have had difficulties with their heating system by incorrect setup or inadequate instructions, which lead to increased electricity demand. Others expected erroneously that when living in a *Low Energy Class 1* building, the energy demand would always be equal to the given in the normative calculated demand of the building, thus without regard to the use by the occupants.

7. References

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