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a case study

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Measurements of energy performance and indoor environmental quality in 10 Danish Passive Houses – a case study

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SUMMARY

The paper describes the first results from a large Danish project regarding measurements of energy performance and indoor environmental quality in 10 Danish Passive Houses. The project includes both qualitative and quantitative analyses. This paper describes the first results from the quantitative part.

The house considered in this paper has an air change rate (ACR) of 0.34 h^{-1} and the results from the first few months of measurements show excellent results when relative humidity (RH) and CO_2-levels are considered. When the temperatures are assessed problems with slight overheating are found. One of the main reasons for this is the low solar angles during spring combined with the lack of solar shading and a low ACR. Solar shading and increased ventilation should be able so solve the problem. The energy consumption for room heating show a very low consumption as expected whereas the energy used for heating domestic hot water is very similar to conventional houses.

KEYWORDS

Measurements, energy consumption, indoor environmental quality, passive houses

INTRODUCTION

During 2008 ten passive houses were built near Vejle in Denmark as a result of the development project "*The Comfort Houses*". The houses are some of the first passive houses in Denmark and all of them will be certified after the German passive house standard (Feist et al. 2005). The 10 houses all have different architectural expressions. Some houses are built as traditional Danish brick houses, some are made from precast concrete units, some with wood casing, some with plaster – all different houses where also different building technological solutions were used (www.komforthusene.dk, 2009). The idea of choosing different constructions of the houses also makes the project unique since it will be possible to demonstrate that passive houses in a Northern European context also can fit into the local architecture and building tradition.

Even though the houses are quite different one thing has to be common for all of them. They all have to comply with the passive house standard, which means having a heat demand lower than 15 kWh/m^2 pr year, a total primary energy consumption lower than 120 kWh/m^2 pr year and finally having an infiltration lower than 0.6 h^{-1} with a pressure difference of 50 Pa. (Feist et al. 2005). Since a very simple way to lower the energy consumption is to lower the air change rate of course this possibility has been discussed during the design phase. Today the Danish building regulations require an air change rate of 0.5 h^{-1} with a standard room height of 2.5 m but the Comfort Houses has obtained an exemption from the regulations and are allowed to lower this down to 0.3h^{-1}.

Lowering the air change rate of course will result in lower heat demands for the houses but it will also increase the risk of poor indoor environmental quality (IEQ). In order to follow this, and also document whether the calculated energy consumption will correspond to the measured value, a program for measurements was set up for the houses. Earlier work within documentation of IEQ and energy consumption in passive houses mainly focuses on the thermal part of the indoor environment (Feist et al. 2001, Schnieders et al. 2006 and Wall 2006) but in this project the atmospherically part will also be included by measurements of relative humidity and CO_2. This is done to ensure that a good and healthy indoor environment has been achieved and has not been overruled by achieving low energy consumption.

METHODS

In order to document the function of the 10 houses both qualitative and quantitative analyses have been applied. The aim of *the qualitative analyses* is to obtain knowledge about the residents, their behaviour in the house and their reasons for buying a passive house. These analyses consist of two separate visits in each of the houses where questionnaires are sent beforehand and followed up by interviews on the day of the visit. The first visit is made just after the taking up residence of the new passive house, with the aim of obtaining knowledge of their earlier (reference) house. The second visit is made after one year of habitation in the house and will focus on their routines and experiences with their life in a mechanically ventilated passive house. The results of the qualitative measurements are not included here.

The quantitative analyses consist of detailed continuous measurements of the indoor environment and the energy consumption in the houses. For assessment of IEQ wireless sensors are used for measurements of room air temperature, relative humidity and CO_2 in living room, kitchen, one or two bedrooms and a bathroom in each house. The measurements regarding energy consumption are carried out in the scullery through both electricity meters and energy meters. The electricity consumption is split into several meters in order to obtain detailed knowledge about the amount of electricity used for ventilation, household, heat pumps etc. The energy meters are split into one part measuring energy consumption for hot water production and another measuring energy send into the house through floor heating, ventilation air or, in some houses, just regular heaters coupled to a heat pump.

The last part of the data collection is measurements made in the ventilation systems, which in most of the houses are included into a compact unit, which also produces hot water. Here humidity and temperature are measured in order to calculate the efficiency of the heat exchanger in the different systems, and also to be able to calculate the COP of the unit and the heat pumps build into some of the systems. Besides the continuous measurements, also measurements of daylight conditions and acoustics are made during single visits to the houses.

Since one of the main aims of the project is to register what happens in the houses and also avoid influencing the daily routines and habits of the residents, it was important to choose equipment that would be “invisible”. Data from the houses are collected and send through the internet to an energy management system (EMS). Here all measurements can be followed from a remote position which also means, that we do not have to visit the houses frequently to empty dataloggers and check equipment. Data is collected every 5th minute throughout the year. The measurements started during March 2009 and will continue for 30 months.

RESULTS

The results presented here will be based on the very first indications. Further details and analysis will follow during the next three years of continuous measurements.

Case study: Single-family house, 145 m^2 net area, 362 m^3 (net volume), 2 adults, 1 child
The house (see Figure 1) is made of brick walls (both inner and outer walls) with 380 mm insulation in between. The main living area is facing nearly south whereas kitchen and bathrooms have northern positions. A floor plan can be seen in Figure 2.

Figure 1. The studied passive house. Façades towards south and east.

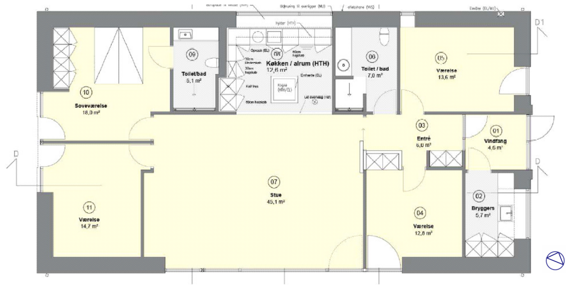

Figure 2. Floor plan

The house is mechanically ventilated with air inlet into "clean" zones (red zones in Figure 2) and air exhaust from the more polluted zones as kitchen, bathrooms and scullery (blue zones in Figure 2). The average air change rate is 0.34 h^{-1}, but the system is demand controlled and the user can manually increase the volume flow by 25% by pushing the "party" button in the living room. This option was used a single time during the first 1½ month of measurements.

Indoor environmental quality
From the very first analyses it is found that high temperatures in the living areas are the main problem. In average the CO_2 level in the house is around 650 ppm and it only gets above 800 ppm a few times (see Figure 3), which must be considered as good in a single family home (corresponds to category I in the European standard EN 15251 (CEN 2007)). This is found for both March and April. Also the relative humidity is found to be acceptable with a maximum of 54%. The minimum value of 22% is a little critical but is only reached for a short period due to the cold outdoor temperatures during night in the same period (see Figure 3 / Figure 4).

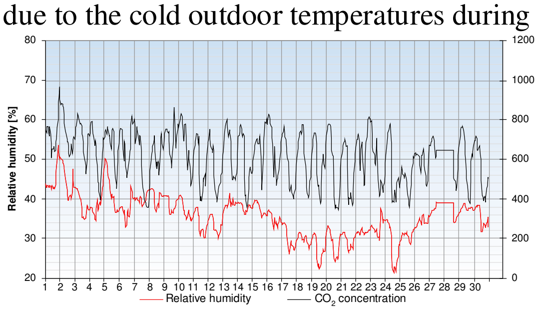

Figure 3. Measured relative humidity and CO_2 concentration during April 2009.

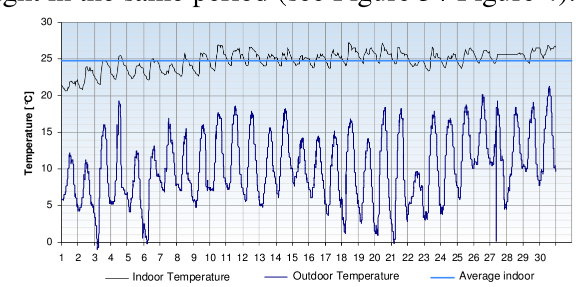

Figure 4. Measured indoor and outdoor temperature during April 2009.

When the indoor temperature is considered, the increasing level of the outdoor temperature and the higher solar gains is reflected directly at the indoor temperature measured during April, which several times are above the level for thermal comfort during this season. The temperature is higher than 26°C for 105 hours which will classify the house as category III according to CEN 2007.

Here a typical problem for passive houses is seen. Since the house is very well insulated it will overheat very fast, and will probably have a great need of solar shading, which in this case is absent. The only shade provided is at midsummer from the overhang above the southern windows of the house (seen in Figure 1). Another solution will be to increase the natural ventilation by opening windows but this solution is limited to the periods where the house is occupied due to the risk of theft.

Energy consumption

The heat demand of the house is covered by an efficient heat recovery cross flow unit in the ventilation system, with a recovery ratio of 75.3% and a possibility to bypass the inlet air manually. Besides the heat recovery unit a supplementary water based heating surface for additional heating of ventilation supply air is used and finally a water based floor heating system in the two bath room floors and a small area in the living room is installed. The water based heating is produced by a ground source heat pump with a COP varying between 3.05 (summer) and 3.58 (winter). During the first 1½ months of measurements the floor heating system has only been activated three times with a total heat consumption of 23 kWh. In the same period the heat consumption for domestic hot water was 220 kWh.

DISCUSSION

A simple way of saving energy is by lowering the ACR and of course this option can be considered when houses are being designed, but it must never become a solution which overrules the demands for a good and healthy indoor environment. Therefore it is important to find the balance between saving energy and obtaining good IEQ. In the search for this balance it is important to consider not only the thermal part of the indoor environment but also the RH and CO_2-levels, which in some parts of the year also will be important factors (Jensen, 2008)

CONCLUSIONS

The first indications of the IEQ in one of the first Danish passive houses show excellent results when both RH and CO_2 are considered. The temperature levels show problems with overheating which mainly are caused by the low solar angles during spring. Solar shading and increased ventilation should be able so solve this problem. The results from measurements of energy consumption for room heating show a very low consumption as expected whereas the energy used for heating domestic hot water is very similar to conventional houses.

ACKNOWLEDGEMENT

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