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A Swedish-German energy efficient apartment building with attached sunspace

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SUMMARY

Two identical apartment buildings were built, one in Germany, and one in Sweden, in 1986. The idea was to create energy efficient housing at a low cost, using Swedish building technology and German heating and ventilation technology. The Swedish building code, which is more stringent in terms of energy conservation than the German one, was applied in both countries. The paper examines the performance of the buildings. The energy consumption (1987-89) for space heating was 45 % less than for a building built according to the Swedish building code and 60 % less than a building built according to the German building code. These energy savings were achieved by insulating the buildings very well and by installing an exhaust air heat pump. Less than 5 % of the total energy savings were due to the sunspace and the thermal mass. The energy efficiency can be further improved.

1. BACKGROUND

The idea was to create resource and energy efficient housing at a low cost, using Swedish building technology and German technology for heating and ventilating. The Swedish Building code, which is much more stringent in terms of energy conservation than the German one, was to be applied in both countries. Two identical apartment buildings were built, one in Ingolstadt, Germany and one in Halmstad, Sweden, in 1986. The experience from Tuggelite (built in 1984 in Karlstad) was used when designing the buildings (1). Tuggelite, with 16 townhouses, was made by and for people, who are very conscious of the energy and environment situation, while the two buildings, in Ingolstadt and Halmstad. are made for "the average person".

Efem Arkitektkontor designed the buildings, while the Swedish National Testing and Research Institute carried out the performance monitoring and evaluation. During 1987-89 temperatures, energy use, and outdoor climate were continuously monitored (2). Short unoccupied periods were used for special measurements.

The climate in the two cities is very similar. Halmstad's November through March temperatures average +0.8 °C, compared with in Ingolstadt +1.0 °C. Both of the cities have the same number of heating degree days. The yearly solar radiation on the horizontal plane is 20 % higher in Ingolstadt than in Halmstad.

2. DESCRIPTION OF THE BUILDINGS

Each building contains three townhouses and 8 apartments. All units have their entrance from the north and an attached sunspace facing south. The total floor area is 935 m^2. The buildings are modern wood frame constructions, built on a slab on grade, with interior structural elements of concrete on the first floor, in order to store some of the internal gains. Space heating is provided by a hydronic heating system with conventional radiators. Heat is distributed from an electric boiler (in Sweden) and a gas-fired boiler (in Germany) located in a heating plant in the building.

Thermal insulation: Mineral wool insulation was installed throughout, in walls, ceilings, and floors. The U-values are much better than in more conventional Swedish and German buildings (table 1). Most windows face south.

Table 1. U-values, conduction coefficients (CC) and building load coefficients (BLC). SBN 80 = the Swedish building code and DIN = the German building code.

U-value W/m^2 °C	Tuggelite	Tested	SBN 80	DIN
Exterior wall	0.12	0.19	0.30	0.70
Ceiling	0.08	0.13	0.20	0.45
Floor	0.12	0.12	0.30	0.40
Window	1.80	1.50	2.00	2.60
CC W/K	-	390	670	1080
BLC W/K (Ingolstadt)	-	700 (910)	1000	1600

Tightness: As a moisture and air barrier, a continuous polyethylene sheet was employed between the insulation and the interior finished wall. The envelope of the building in Halmstad is very tight and all 11 units satisfy the Swedish building code requirement for airtightness, 2.0 air changes per hour at 50 Pa. The airtightness in Ingolstadt ranges from 1.5 to 5.0. The workmanship was not as good as in Halmstad due to lack of experience in building tight.

Heat recovery: The two buildings have a mechanical ventilation system, which exhausts 0.5 air changes per hour of used air. The greater part of the outdoor air is assumed to be preheated in the attached sunspace. Heat is recovered by an exhaust air heat pump and used to heat domestic hot water.

3. RESULTS

3.1 Energy Balance

During 1988 the 11 units in Halmstad used 46 kWh/m^2 and in Ingolstadt 48 kWh/m^2 for space heating (see fig. 1). The consumption of electricity for household use was 22 kWh/m^2 in Halmstad and 26 kWh/m^2 in Ingolstadt. The heating of domestic hot water (excl. standby losses) required 22 kWh/m^2 in Halmstad and 18 kWh/m^2 in Ingolstadt. The use of electricity of the heat pump was 10 kWh/m^2 in Halmstad and 14 kWh/m^2 in Ingolstadt, while the heat losses from the domestic hot water system were 4.5 kWh/m^2 respectively 23 kWh/m^2 (the water temperature was too high etc). The use of electricity for fans etc. for the apartment building in Halmstad (with a shared laundry) was 31 kWh/m^2 and in Ingolstadt (without a shared laundry) was 15 kWh/m^2. In order to determine the space heating actually delivered to the 11 units a correction has to be made for pipe losses to the attic. After this correction space heating amounts to 43 kWh/m^2 for both apartment buildings.

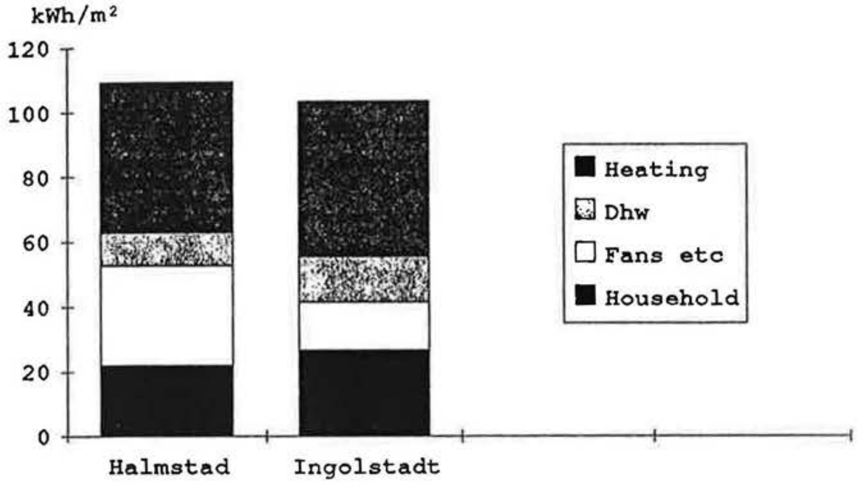

Figure 1. Purchased energy during 1988. For dhw is given the electricity use of the heat pump and for household the electricity use in the apartments.

The energy required for space heating during 1988 was almost the same in Halmstad and Ingolstadt. This although the ventilation and pipe heat losses are larger in Ingolstadt. The following four factors have prevented an increase in Ingolstadt: higher internal generation of free heat, lower indoor temperature, a milder heating season and more solar energy during the heating season than in Halmstad.

The buildings were modelled using STAWAD (3). As inputs were used measured outdoor air ventilation rates, air flows through the sunspace, air temperatures in the sunspace, internal generation of "free heat" and hourly weather data measured at the site. A fairly close correlation between the measured and calculated energy consumption for space heating was obtained. The calculated yearly value was 45 kWh/m^2 compared with the measured one of 42 kWh/m^2 for Halmstad. In Ingolstadt the calculated value was 42 kWh/m^2 and the measured value 43 kWh/m^2.

The first step was to determine the energy consumption for space heating, when the indoor temperature is +20 °C. In Halmstad there is a reduction of 7 kWh/m^2 from 45 kWh/m^2 to 38 kWh/m^2 (see fig. 2). The next step was to use a different climate, as the monitoring year was warmer than is usual. The reference year 1971 of Stockholm raised the consumption by 20 % to 45 kWh/m^2. The standard weather year of München raised the consumption of Ingolstadt by 15 % to 49 kWh/m^2.

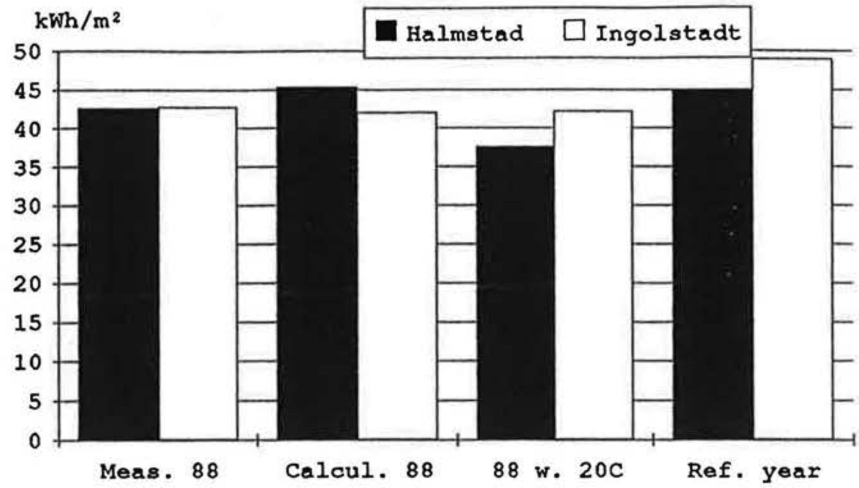

Figure 2. Yearly energy use for space heating: measured 1988, calculated for 1988, for 1988 with 20 C, and for a Swedish and German reference year.

The energy consumption can for Halmstad be compared with the design calculation of 43 kWh/m^2. The design calculation assumed an internal generation of "free heat" of 9 kWh/m^2 instead of the actual of 31 kWh/m^2. The difference between design and actual energy consumption can partly be explained by the error in assuming that most of the outdoor air would enter through the sunspace and the overestimation of the savings due to the thermal mass.

3.2 Thermal mass

The energy savings due to the thermal mass were calculated by STAWAD to be only 0.1 kWh/m^2 for the entire building. When the space heating demand is high, there is very little excess internal generation of "free heat" that can be stored. The indoor temperature is almost constant. During the time of the year when the solar radiation through the windows gives a considerable contribution, the space heating demand is so low that the stored heat does not mean any significant savings. This is true for very well insulated buildings with moderate amounts of "free heat".

If the energy savings due to thermal mass had been the same as in Tuggelite, the savings would have been between 0.4 and 2.7 kWh/m^2. All the interior walls and floors are made of concrete in Tuggelite. The energy savings are modest, the main advantage with the thermal mass in these buildings is a certain damping of the diurnal variation of the indoor temperature.

3.3 Sunspace

The sunspace contributes in two ways to the space heating of the apartment building, by preheating of the outdoor air and by reducing the thermal losses through the walls.

For the monitoring year the reduction in ventilating losses for the entire building was calculated to be 1.4 kWh/m² (Halmstad) and 1.6 kWh/m² (Ingolstadt) and the reduction in conduction losses to be 1.6 (Halmstad) and 1.4 kWh/m² (Ingolstadt). The overall reduction corresponds to a reduction in space heating of between 1.8 and 3.6 kWh/m². According to measurements only 1/5 (Halmstad) and 1/6 (Ingolstadt) of the outdoor air enters through the sunspace. In Tuggelite the energy savings due to the sunspace was 450 kWh per apartment, which would correspond to 3.2 kWh/m² for Halmstad-Ingolstadt.

The temperature in the sunspace varies very much during the year. Large diurnal variations have been observed. The temperature rises almost as soon as the sun appears, even during cold winter days. When the sun disappears, the temperature drops. During spring and autumn the temperature can be comfortable.

3.4 Indoor Climate

The overall ventilation rate is adequate. The occupants can control where 40 % of the outdoor air enters the building (with windows and doors closed). The remainder of the outdoor air enters through cracks. The indoor temperature is rarely above +25 °C. During cold days some cold draft might occur below the outdoor air vents.

3.5 Energy Comparison with Conventional Buildings

To understand these buildings in their context, they were compared with conventional buildings (see fig. 3), carefully built buildings with the same floor area, but without sunspace and insulated according to the Swedish and German building codes (see table 1). The energy use for space heating in the comparison building was calculated using the same assumptions as for the tested buildings. The comparison building

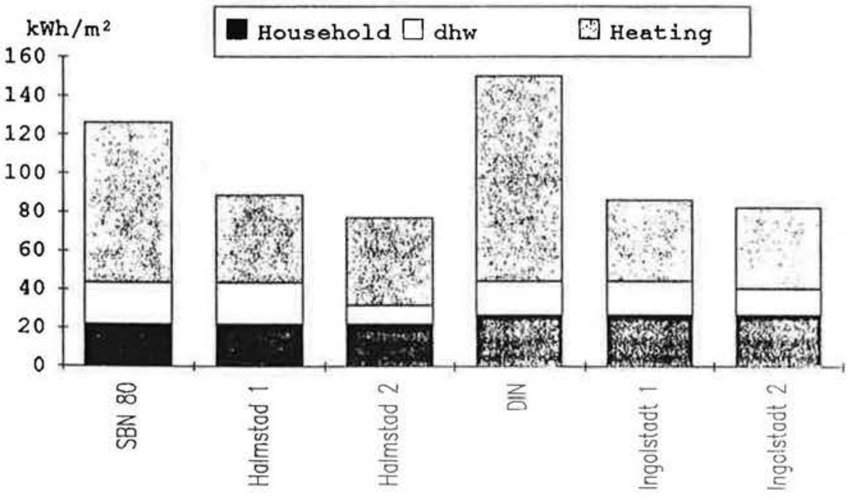

Figure 3. Calculated yearly energy use for the two buildings for 1988, built according to resp. building code and as built. Only the last calculation is with heat pump.

used 80 % more in Sweden and 150 % more in Germany than the tested building.

4. CONCLUSIONS

The monitoring of the two buildings has shown that it is possible to build well functioning multi-family buildings in Sweden and in Germany with very good insulation, good airtightness, some thermal mass and attached sunspaces (4). The conventional heating system and exhaust fan ventilation system led to a comfortable indoor climate. The energy savings were achieved by insulating the apartment buildings very well and by installing a heat pump. Less than 5 % of the total savings are due to the sunspace and the increased thermal mass. The building costs in Ingolstadt were similar to conventional multi-family buildings.

Performance of the two buildings could be improved. Suggestions include:
- Use the free capacity of the heat pump (50 % of the time) for space heating

- Reduce the number of storage tanks by 50 % in the heating plant
- Improve the system for bringing outdoor air into the apartments
- Install energy conservative appliances

The two first measures were carried out after the measurements were finished.

The experience from this project and other similar projects point to certain basic principles which should be followed when designing and building low energy buildings. The buildings should be made for people, adapted to the surroundings, aesthetic, dry built, built of healthy materials, "airtight", well-insulated, guarded against overheating, passive solar, eventually equipped with a sunspace, mechanically ventilated, equipped with heat recovery, equipped with energy conservative appliances, heated by a simple heating system, and a well functioning system.

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