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EVALUATION OF ENERGY SAVINGS BY MEASUREMENTS WHEN IMPLEMENTING EXTENSIVE ENERGY CONSERVATION MEASURES IN NINE BLOCKS OF FLATS

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Introduction

The Guldheden Project (1,2) is one of six similar projects, which have been going on in Sweden for the last four years in multifamily houses at different places. They have all been initiated by the Swedish Council for Building Research.

The objective was to implement various energy conservation measures (ECM) and, by advanced measurements, evaluate the savings and profitability from different combinations of such measures. Another important objective was to study and document the planning, design and implementation process and the prospective obstacles to this kind of measures.

A final evaluation of the implemented measures was carried out during 1985. Since then, we have continued our measurements, but now with less intensity and control. This paper presents the Guldheden Project and some of the results from the final evaluation and what has happened during the heating season 1985/86.

Description of the buildings

The Guldheden Project consists of nine similar houses, which are situated in Gothenburg, where the annual average outdoor temperature approximately equals +7 C.

A short description of the buildings is given in Figure 1 together with some basic data concerning U-values etc before retrofits.

Implemented measures

In order to equalize the houses, as much as possible, before carrying out the extensive measures, a number of more basic ECM were implemented in all houses. They included adjustment of the heating and ventilating systems, flow rate regulators

for cold and hot tap water, windproofing of windows, and additional thermal insulation of the attic with blown mineral wool. This kind of measures are commonly used in Sweden for this type of buildings at the beginning of the energy saving process.

In two of the houses, no additional measures were carried out. These houses are used as "reference objects" to the other seven "test objects", where different combinations of other measures were implemented (Figure 2).

Additional thermal insulation of external walls with 0.12 m mineral wool reduces the U-value to approx. 0.30 W/m2,K. The other houses will be insulated later on with the same technique.

Conversion of windows, by adding an extra pane on the inside of the casement, reduces the U-value to approx. 2.10 W/m2,K. New triple glazing in stair enclosures was mainly a consequence of the retrofit of external walls.

The exhaust air heat pumps are used for both tap water heating as well as for space heating. Two different operating strategies can be used, where priority is given either to tap water heating or to space heating.

Measurements and evaluation methods

Extensive measurements of parameters affecting the energy balances of the buildings have been carried out during more than four years. For example, the energy consumption for space heating and for tap water heating were measured once a week in each house, as well as the energy consumption for laundry driers and the consumption of cold and hot tap water.

Temperatures in apartments and stair enclosures, of exhaust air, inside and on the external walls as well as the outdoor temperature, were measured continously using microcomputers.

Additional measurements were also carried out for the heat pumps, in order to evaluate the coefficient of performance (COP) and the seasonal performance factor (SPF).

Two methods are used to evaluate the the savings, the before-after method and, as a complement, the test-reference method (3), according to the experimental design plan in Figure 2.

Annual energy consumption for space heating has been calculated using the energy signature technique (3). Different models for the energy signature have been used.

When using the energy signature of a house, it is easy to evaluate the energy savings also for a "normalized" indoor temperature, even if you do not always reach that specific level. This method to recalculate the measured energy savings, is valuable when you want to analyze the savings from a specific measure, implemented in houses with different indoor temperatures. We have used a "normalized" temperature of +20.5°C, together with real measured indoor temperatures.

Energy savings for different combinations of measures

Some preliminary results have been reported (4,5) and some final results (6). In this paper we will give an overview of the most important final results.

Analyzing bought energy for space and tap water heating for each house, before and after retrofits, we have achieved results according to Figure 3. As can be seen from this figure, the energy consumption varies between the houses before retrofits, mainly due to differences in indoor temperature and air change rate. This of course has affected the energy savings for identical combinations of measures.

Measured data from Figure 3, indicate energy savings of approx. 15-45 %, based on the energy consumption before retrofits. All figures are based on the area of the apartments including the stair enclosures.

To analyze the energy savings for different ECM correctly, however, you have to analyze the energy consumption for space heating separately. Our measurements have namely shown that the energy consumption for tap water heating and for laundry driers have changed during the experiment . These changes will affect the energy savings for such measures as additional thermal insulation, conversion of windows etc.

These are some of the results of such an analysis of different combinations of measures:

- The basic measures have provided savings of approx. 40 kWh/m2,year, with a range of variation between 30 kWh/m2,year and 45 kWh/m2,year.
- The combination of basic measures, triple glazing in stair enclosure and exhaust air heat pump, provided savings of approx. 60 kWh/m2,year. Here we have taken into account the reduction of the energy consumption for space heating,given by our concept for the exhaust air heat pumps.
- The combination of basic measures, additional thermal insulation of external walls, conversion of windows to triple glazing and new triple glazing in stair

enclosures, provided savings of approx. 85 kWh/m2,year.

- The "total retrofit" provided savings of approx. 100 kWh/m2,year with the same conditions for the heat pump as above.

For those houses, where we have been able to analyze the energy savings for single measures separately, we have the following results:

- For new triple glazing in stair enclosure, no guaranteed savings have been provided.

- Conversion of windows to triple glazing, have provided savings of approx. 15 kWh/m2,year. At our "normalized temperature" (+20.5 ^{o}C), the savings would have reached the level 20 kWh/m2,year.

After the final evaluation, we have continued some measurements for 1.5 years. The energy consumption for space heating, seems to have increased with approx. 4 % as an average during 1985/86 for most of the houses compared to the results from 1984/85. This is valid at the "normalized" indoor temperature. For house 1 we have got a decrease of approx. 3% instead.

The decrease in house 1 seems to correspond well to that amount of energy, which we have calculated to be the demand to dry out the moisture in the old external walls during the first year after the implementation of the additional thermal insulation.

During 1985/86 our monitoring and control have been carried out with less intensity than before. Surely, this fact can explain some of the increases mentioned above.

Some of the increase in house 4 , however, can be explained by the fact that the average outdoor temperature in January and February 1986 was approx. 5^{o}C lower than at the same time in 1985. The exhaust air heat pump, namely, can not deliver any energy for space heating when the outdoor temperature is extremely low. This fact does not affect the heat pump that much in house 9, because there we have been able to lower the water supply temperature to the radiators more than in house 4. This has been possible, because of the "total retrofit".

Energy savings for the exhaust air heat pumps

The output of the exhaust air heat pumps in houses 4 and 9 is approx. 25 kW each. During the heating season 1985/86 the operational time was approx. 7000 h in both houses.

Approximately 55 % of the total energy output from the heat pumps has been delivered to tap water heating and approx. 45 % to space heating. The COP was measured to approx. 3.2, considering only the heat pumps, and approx. 2.5, also considering the auxiliary pumps etc.

The net average energy savings from the installations of heat pumps have reached a level of approx. 35 kWh/m2,year.

The variation of the COP for different periods during the heating season is shown in Figure 4. As can be seen from this figure, the COP for the complete installation is extremely lower in the summer than in the winter. It depends on an extra fan, installed to compensate for the pressure drop over the filter and the cooling coil, which is operating during the whole year.

Comparison between measured and calculated energy consumption data after retrofits

In the beginning of the energy saving process, you have to carry out some calculations both of the expected energy savings and the economic profitability. In order to analyze which differences you get between measurements and calculations, we have carried out some calculations with the computer model MSA (7), which in some parts is based on the BKL-method (8). This model uses monthly energy balances as a base for the calculations.

As a result of this analysis, differences of approx. +/- 10 % occurs in houses, where few measures have been implemented and up to - 20 % in house 9, where the "total retrofit" was implemented.

The differences seem to be greater in houses with more comprehensive measures implemented than in others. Besides imperfections of the model and errors in the measurements, we have come to the conclusion that mainly four other factors can contribute to an explanation. These factors are:

- Moisture in the external walls.

- Extra shading effects of the windows when the external walls were insulated and the old windows were not moved out to the facade.

- The length of the heating season is shorter in theory than in practice.

- The absorption of solar energy is greater for the old surface of plaster than for the new one of sheet metal.

Correcting the calculations for these extra energy demands, you get differences of about +/-15 % for all houses. This is a good agreement.

Conclusions

The Guldheden Project has shown, that large energy savings can be achieved in existing multifamily houses, when extensive ECM are combined and well fitted to the specific houses.

Measurements, carried out for more than three years after the implementation of measures, have shown that as an average these savings also remain. However, there is a risk that the savings will decrease, if you stop monitoring the buldings.

Good agreement can be achieved between calculated and measured data of energy consumption. However, you have to use a good model, know its limitations and use input data of good quality.

None the less, the most important thing is to implement the measures in a correct way and to control them very carefully, preferably by using some kind of an energy management system.

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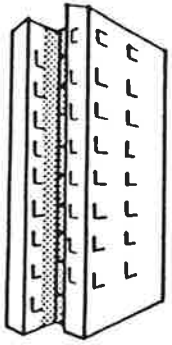

General	∘ Nine houses built 1952-1953. ∘ Eight to ten storeys. ∘ 332 apartments.
External walls.	∘ Concrete, lightweight concrete as insulation, surface of plaster. ∘ U-value 0,92 $W/m^2,K$
Attic floor	∘ Concrete, mineral wool. ∘ U-value 0,71 $W/m^2,K$
Windows	∘ Two pane, linked casement.
Heating	∘ District heating system, separate apparatus rooms in each house.
Ventilation	∘ Mechanical exhaust air. ∘ Air change rate approx. 0,8 h^{-1}.
Temperatures	∘ Apartments 21,3 °C (average).

Figure 1. Description of buildings before retrofits