THE GULDHEDEN PROJECT: A FULL-SCALE STUDY OF ENERGY-CONSERVATION MEASURES IN NINE BLOCKS OF FLATS

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ABSTRACT

Various energy conservation measures (ECM) have been implemented in the form of different combinations in nine equal existing blocks of flats in Gothenburg, Sweden. The implemented measures are basic measures on the installation, additional thermal insulation of external walls, conversion of windows to triple glazing, and exhaust air heat pumps.

The different combinations of ECM have been evaluated by carrying out a lot of measurments of temperatures, energy consumption, etc., using newly developed microcomputer techniques.

Calculations of the energy consumption after implementing ECM have been carried out and compared to measured data. Good agreement has been achieved between calculations and measurments if one also takes into account moisture in the external walls, "extra" shading effects of the windows, etc.

The saving effects of implemented ECM vary between 15% and about 50% of the total energy consumption before retrofits, mainly depending on the implemented combinations and the occupant behavior in each house.

INTRODUCTION

The Guldheden Project (BFR 1983; Nilson 1984, 1985; Nilson et al. 1984) is one of six similar projects initiated by the Swedish Council for Building Research (BFR). The objective is to implement various energy conservation measures (ECM) in existing residential buildings and, by advanced measuring, evaluate saving effects and profitability for different combinations of these measures. Another important objective is to study the planning, design, and implementation process and prospective obstacles to this kind of measures. Preliminary results from these projects have recently been used in the so called Energy 85 revision of the Swedish national program for energy conservation and energy policy (BFR 1985).

This paper presents the project and some of the results.

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BUILDING DESCRIPTION

The houses are situated in Gothenburg with an annual average temperature of about +7.0°C. The hard climate on the Swedish west coast with driving rain and hard wind had caused severe damage to the plaster so the external walls had to be repaired. This fact is of great importance to have in mind when evaluating the profitability of the extensive measures in this project.

A short description of the buildings is given in Figure 1.

IMPLEMENTED MEASURES

In order to equalize the houses as much as possible before carrying out extensive measures, a number of basic ECM were implemented in all houses. These basic measures comprised 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. These kinds of measures are commonly used in Sweden for this type of building 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 insulation of external walls with 0.12 m mineral wool and a new surface of sheet metal cassettes reduces the U-value to 0.30 $W/m^2 \cdot K$. 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 2.10 $W/m^2 \cdot K$. New triple glazing in stair enclosures is mainly a consequence of the retrofit of external walls.

The heat pumps are used for both hot tap water heating and space heating, thus providing a high degree of utilization and a high seasonal performance factor (SPF). Two different operating strategies can be used where priority is given either to tap water heating or to space heating (Figure 3).

MEASUREMENTS

Extensive measurments of parameters affecting the energy balance of the buildings have been carried out. For example, energy consumption for space and hot tap water heating, water consumption, and energy consumption for laundry driers are measured once a week in each house. Electric consumption for the occupants is measured once a year. Temperatures (instantaneous and mean values) in apartments, stair enclosure, exhaust air, outside, in and on external walls are measured continously using microcomputers.

Additional measurments are also carried out for the heat pumps in order to evaluate the coefficient of performance (COP) and the SPF.

Two methods are used to evaluate the saving effects, the before-after method and as a complement the test-reference method (Fracastoro and Lyberg 1983) according to Figure 2.

Annual energy consumption for space heating has been calculated using the so-called energy signature (Fracastoro and Lyberg 1983; Norlén et al. 1981). Different models for the energy signature have been used in the project in order to predict the energy consumption for each house before and after retrofits. Both simple linear two-parameter models (function of only outdoor temperature or the difference between indoor and outdoor temperature) and more complex models that also take solar radiation into account have been used. Because of measuring the energy demand for hot tap water heating and laundry driers separately, the energy signatures used express energy consumption for space heating at different temperatures or differences between temperatures. To get the total energy consumption for each house, the energy demands mentioned above have been added separately.

All models used have given good agreements between predicted and measured energy-consumption data for the whole heating season. The linear curve fitting to measured data has given coefficients of determination (R^2) greater than 0.95.

When using the energy signature to predict the energy consumption for a house before and after retrofits, it seems that the most simple two-parameter model (function of outdoor temperature) would be enough in many cases. However, a two-parameter model with function of the temperature difference between indoor and outdoor air will give us more information of a specific ECM and the separate saving effect for this measure.

When carrying out the final evaluation of different combinations of ECM, we used this model as our basic one (Figure 4).

Mainly because of small amounts of solar radiation in Gothenburg during the last heating season, our most complex model has not given better predictions than the two other models used studying the entire heating season.

ENERGY SAVINGS

The outcome of the basic measures, implemented in identical houses, varies due to differences in indoor temperature and air change rate before retrofits. Occupant behavior, such as water consumption and airing, also affects the results. On average the basic measures reduced the energy consumption from approximately 270 $kWh/m^2 \cdot yr$ to approximately 230 $kWh/m^2 \cdot yr$ (15%).

In house 9, where all measures have been combined in a so-called "total retrofit," the energy consumption was reduced from approximately 270 $kWh/m^2 \cdot yr$ to approximately 135 $kWh/m^2 \cdot yr$ (50%) (including additional electric energy for the heat pump). Figure 5 shows the total energy consumption before and after retrofits according to Figure 2.

The results presented in Figure 5 are from the 1983/84 heating season. During the last heating season (1984/85), the windows in house 1 and 2 were converted to triple glazing as shown in Figure 2. The energy consumption for these houses has therefore decreased a little bit. For house 9 ("total retrofit") the energy consumption increased instead, mainly because of some problems with the circulation pumps for the heat pump and less intensity in monitoring these systems than before.

Figure 5 presents the <u>total</u> energy consumption for each house, and it is very important to consider this when comparing the results, mainly because the occupant behavior varies between the houses.

HOT TAP WATER SAVINGS AND ENERGY DEMANDS FOR LAUNDRY DRIERS

The energy demand for hot tap water heating before and after basic measures is shown in Figure 6. If you look at the middle age of the occupants in each house and try to find some correlation between the middle age and the energy consumption, you will not find any strong one. The only thing you can find is that the maximun for this energy demand has occured in house 8, where the middle age is lowest and where most people are living.

As an average for all houses, the energy consumption for hot tap water heating decreased about 3% after the implementation of basic measures during 1982. This decrease is lower than expected (15%). However, the decrease in house 5 is 12% and therefore almost reaches the expected level. For house 8 we have an increase of 8% instead. These large variations between the houses implies that occupant behavior affects the water consumption more than technical measures.

No ECM have been implemented for the laundry driers yet. However, Figure 7 shows other interesting results dealing with occupant behavior if studying the energy consumption for these in different houses.

These two houses represent the "high consumer" and the "low consumer" and the ratio between these two extremes is about 1.5:1. These results lead us to conclude that it is very important to measure such energy demands separately to get a better evaluation of ECM.

HEAT PUMPS

The chosen solution provides very long operational time, 95-100% of total time during the heating season. For the last heating season (1984/85) the total operational time for the heat pumps varied between 6320 h (house 9) and 6900 h (house 4). The net energy saving effect has become approximately 35 kWh/m^2.yr as an average. The COP was measured to approximately 3.2, considering only the heat pump, and approximately 2.5, considering the auxilliary pumps, etc.

If you study the outcome for the 1983/84 heating season the results were a little bit better (operational time, net energy savings, etc.). The main reason for this were some problems with the circulation pumps in house 9 and the fact that during the last heating season we have begun to "leave" the area and the control more and more.

The difference of operational time between the two heat pumps is, however, not only dependent on the problems mentioned above. Theoretically, the operational time for the heat pump in house 9 ("total retrofit") will be less than for the heat pump in house 4 because of more E C M implemented in the former one.

Since there is still an overcapacity in the summer, there are discussions on also supplying other houses with hot tap water, heated by the installed heat pumps. However this can lead to some conflicts with the district heating company.

COMPARISON BETWEEN MEASURED AND CALCULATED ENERGY CONSUMPTION AFTER IMPLEMENTATION OF ECM

Calculations of the energy consumption after implementing ECM have been carried out for the different houses and the calculations have been compared to measured data.

The calculations were done with the computer model MSA (Nilson 1985), which in some parts is based upon the BKL-method (Adamson and Källblad 1984) that uses monthly energy balances as a base. The model takes into account the influence of heat gains from occupants, household, solar radiation, etc., as well as the type of glazing and number of panes, orientation, slope, shading from other buildings, and the surroundings. However the model disregards energy storage in walls, etc.

Some of the results are presented in Figure 8. From this figure, it appears that the difference between calculated and measured energy consumption is smaller than 10% for most of the houses, except for houses 1, 5, and 9, where the most extensive measures have been implemented.

To study why the difference seems to be greater in these houses than in the others we have tried to discern all factors that can contribute to an explanation. We have come to the conclusion that four factors mainly contribute to this. These factors are:

1. The external walls contain a lot of moisture because of the damage mentioned earlier and they have not dried out yet. The energy for the drying process is taken from the inside, and, because of the wall construction (concrete, lightweight concrete), this process will take a long time. Calculations of this extra energy demand have been carried out, showing it will reach an amount of about 10 MWh for the first year for a house like this.

2. When you implement thermal insulation of the external walls and do not move the windows to the facade, you get extra shading of the windows. Calculations have showed that this shading effect actuates the total energy consumption with about 10 MWh/yr for these specific houses. Our basic calculations did not take this kind of shading effect into account.

3. Theoretically the heating season will be shortened when implementing ECM. In reality in Sweden you do not always take this into account. For a house in this project, where we know from experience and measurements that the house has been heated longer than the calculations, this extra energy demand will be about 5 MWh/yr.

4. When changing the surface of the facade from plaster to sheet metal, the absorption of solar radiation is reduced. This will increase the energy demand for space heating. To evaluate this amount, calculations have been done with a complex computer model. This extra energy demand is about 5-10 MWh/yr. Our basic model did not take this into account.

Summing up these extra energy demands, the calculated energy consumption will be about 30-35 MWh/yr greater than before. This means that the difference in reality will be less than 15% for these houses, and, therefore, the conclusion is that the difference between calculations and measurements is less than 15% for all houses, which is good agreement.

ECONOMIC PROFITABILITY

As mentioned earlier, another objective was to evaluate the profitability of the ECM. The total investment costs for the measures in the project have reached about 15 million SEK excluding taxes. The grants and loans have reached about 7 million SEK of these. The rest has been paid by the houseowner.

The profitability has been evaluated by carrying out calculations of the cash flow in present values for the combinations of ECM implemented in different houses and taking into account different grants and loans that houseowners in Sweden get from the government when saving energy.

As an example, the calculations for house 9 ("total retrofit") showed that the combination of ECM was profitable when taking the damage of external walls into account. Otherwise this combination would not have been profitable.

CONCLUSION

The Guldheden Project shows that large energy savings can be achieved in existing residential buildings when extensive ECM are combined. If these kinds of measures are coordinated with repair work and reconditioning, they can be carried out economically. This conclusion is also the point for the running energy conservation program in Sweden.

Good agreement can be achieved between calculated and measured energy consumption data if you use a good model and input data of good quality and also take practice and special energy demands into account. The project also points to the fact that all buildings are unique, which is especially important to remember when ECM are planned.

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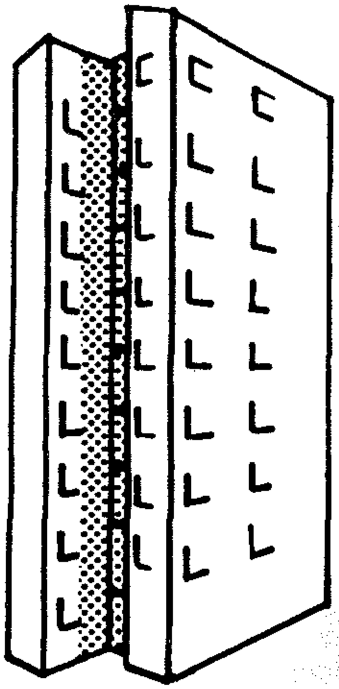
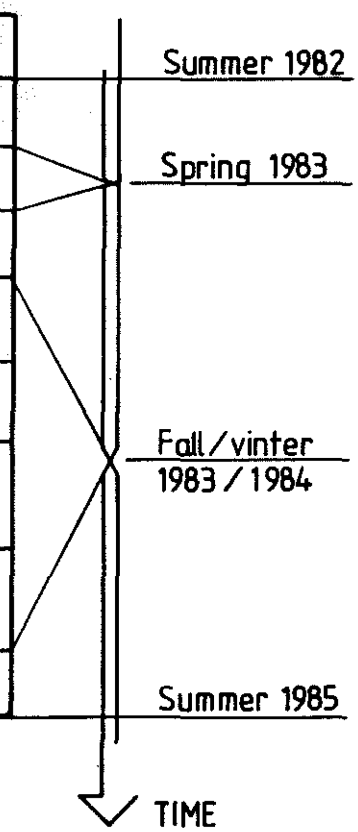


General	o Nine houses built 1952–1953. o Eight to ten storeys. o 332 apartments.
External walls	o Concrete, lightweight concrete as insulation, surface of plaster. o U-value 0,92 $W/m^2,K$
Attic floor	o Concrete, mineral wool. o U-value 0,71 $W/m^2,K$
Windows	o Two pane, linked casement.
Heating	o District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

Figure 1. Building description before implementation of ECM

MEASURES \ HOUSE NR	1	2	3	4	5	6	7	8	9
MEASUREMENTS									
BASIC MEASURES	X	X	X	X	X	X	X	X	X
MEASUREMENTS									
EXHAUST AIR HEAT PUMP			REFERENCE HOUSE	X				REFERENCE HOUSE	X
ADDITIONAL INSULATION OF WALLS	X				X				X
CONVERSION OF WINDOW TO TRIPLE GLAZING WITH EXTRA PANE	(X)	(X)					X		X
NEW TRIPLE GLAZING IN STAIR ENCLOSURE	X	X		X	X	X			X
MEASUREMENTS									



Measures marked (x) have been carried out in summer 1984

Figure 2. Implemented ECM and time schedule

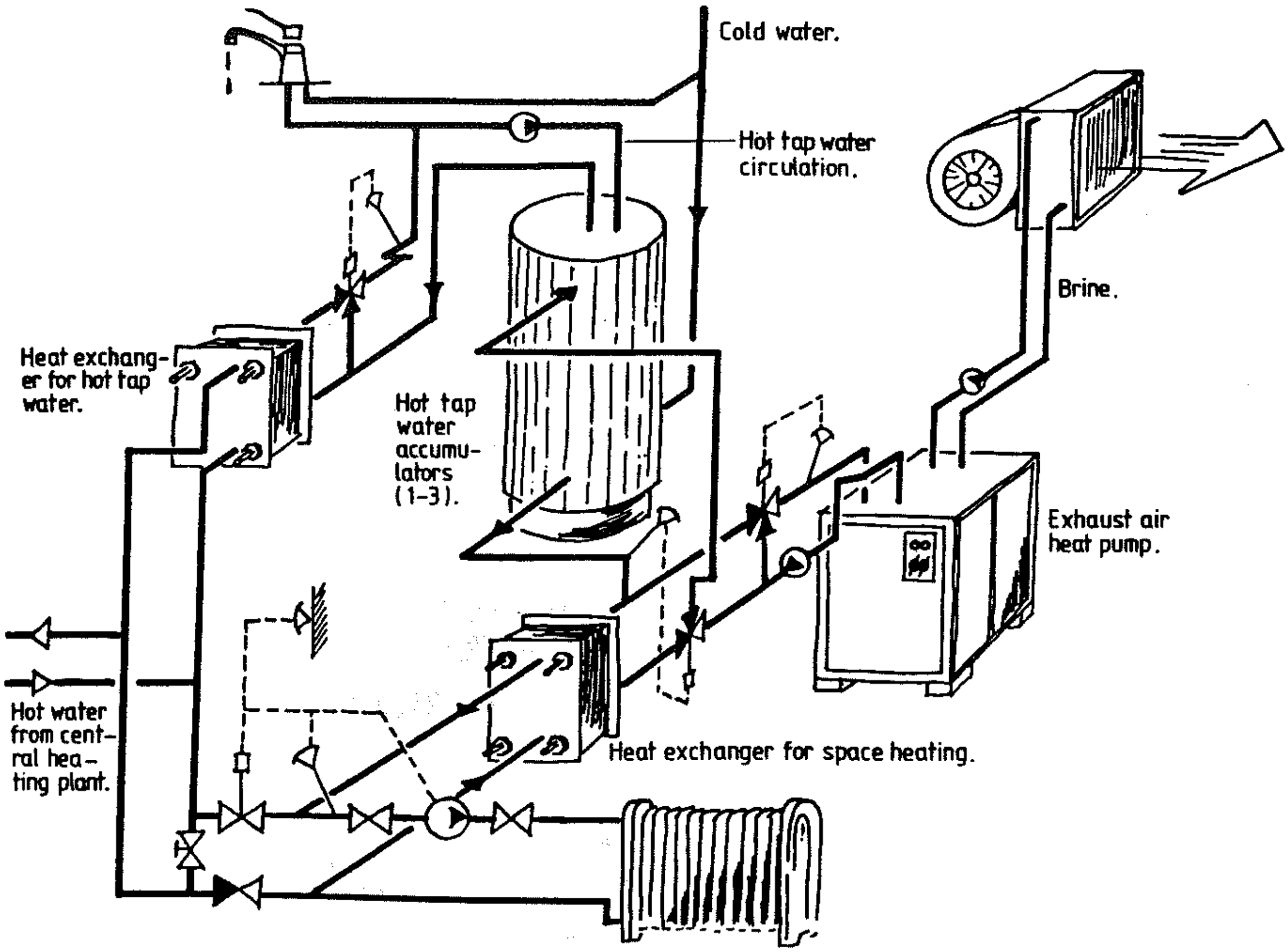


Figure 3. Principle outline of exhaust air heat pump system

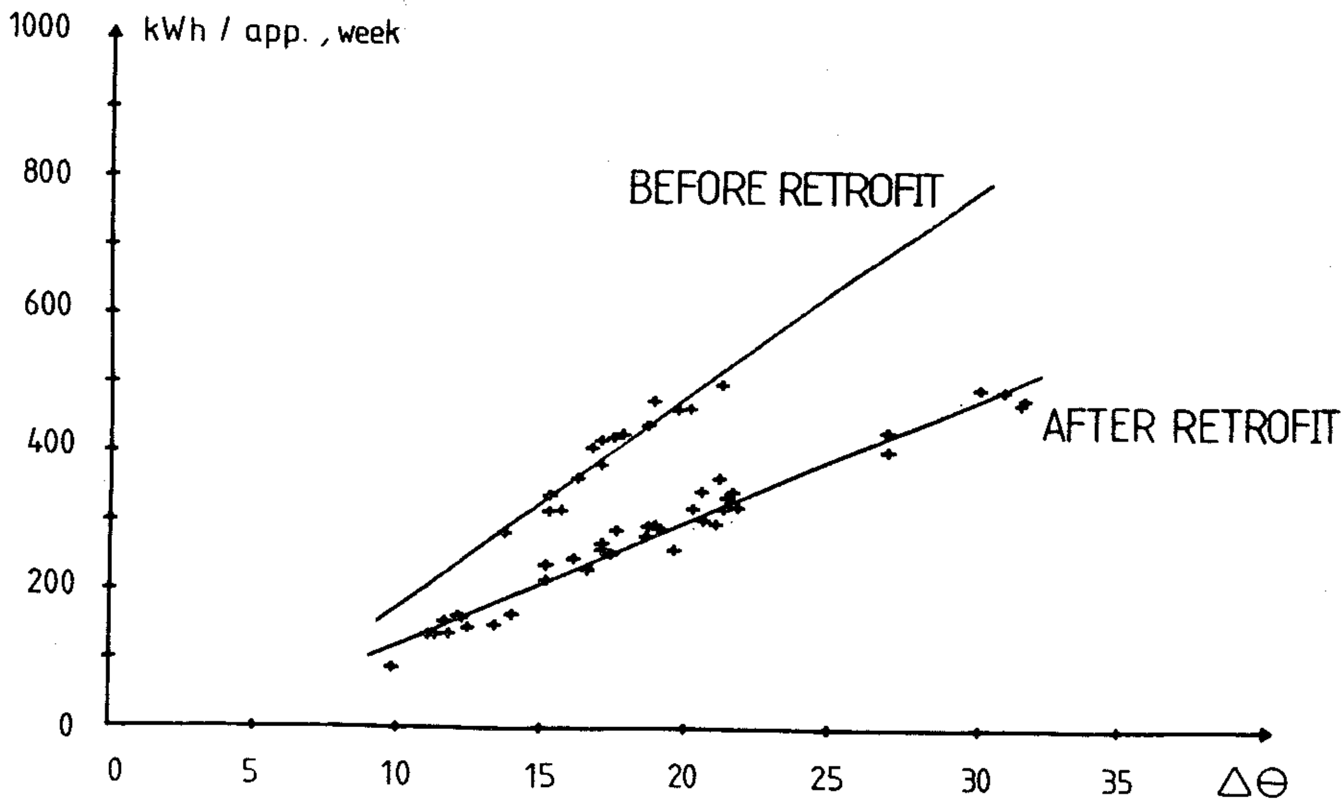


Figure 4. Energy signature for house 9 ("total retrofit")

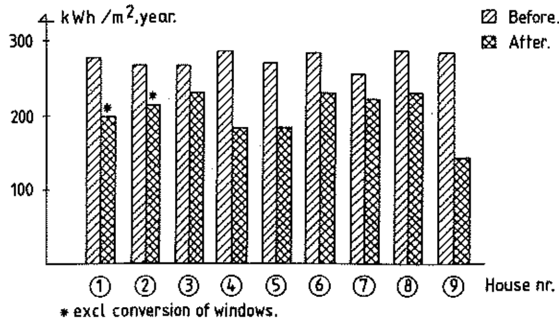


Figure 5. Measured energy consumption for each house before and after implementation of ECM

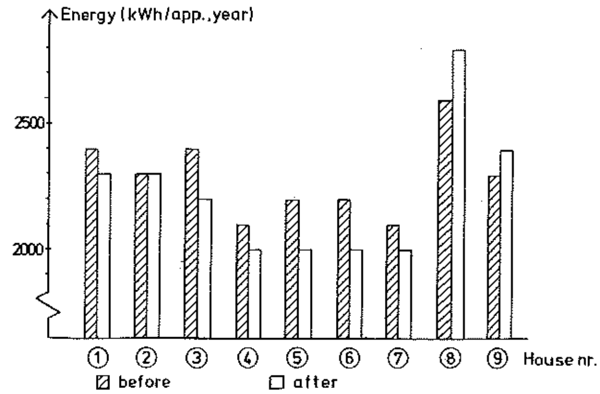


Figure 6. Energy consumption for hot tap water heating

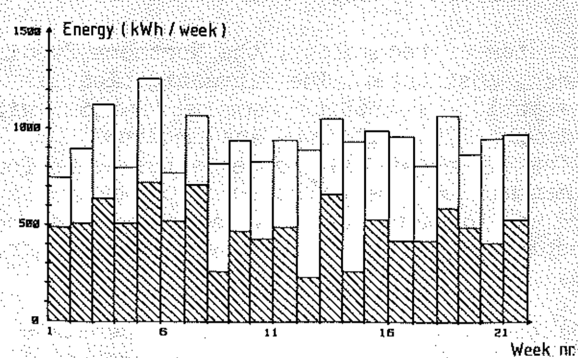


Figure 7. Energy consumption for laundry driers in two houses during same period of time in 1985

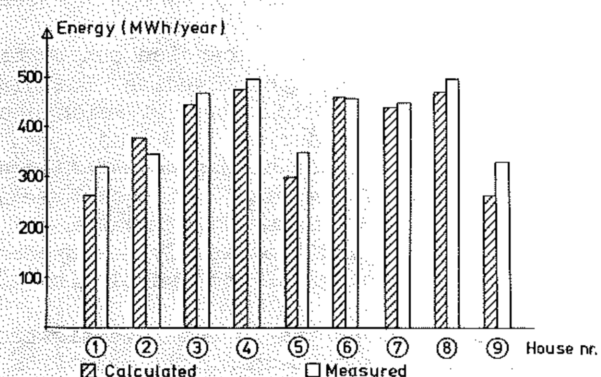


Figure 8. Comparison of calculated and measured energy consumption for space heating after implementing ECM