THE GULDHEDEN PROJECT. EVALUATION OF EXTENSIVE ENERGY CONSERVATION MEASURES IN NINE BLOCKS OF FLATS BY MEASUREMENTS

Anders Nilson and Anders Walter
Bengt Dahlgren AB

ABSTRACT

The Guldheden Project is a full-scale study of the effectiveness of different combinations of energy conservation measures in nine similar blocks of flats, situated in Gothenburg on the Swedish west coast.

The implemented measures have been combined in different ways in the houses. Both basic measures, such as adjustment of the heating and ventilating systems etc, and more extensive measures, such as additional thermal insulation of external walls, triple glazing and exhaust air heat pumps, have been used.

This project is one of six similar projects, which have been going on in Sweden for the last four years. They have been initiated by the Swedish Council for Building Research (BFR).

In order to evaluate the energy savings, a before-after experimental design has been used in combination with a test-reference method. A lot of extensive measurements have been carried out. The collection of data is based on a microcomputer system, specially designed for these projects and further developed for the Guldheden Project.

All measures used in the project, have been combined in a "total retrofit" for one of the houses. In the others, the combinations used vary in extension between only basic measures and more extensive combinations.

The use of energy after the implementation, has been measured for almost three years now. During these years, we have been able to evaluate the effectiveness and its variations. Studying data from the heating season 1984/85, we have reduced the energy consumption from approx. 260 kWh/m^2,year to approx. 225 kWh/m^2,year, when only basic measures were implemented and to approx. 145 kWh/m^2,year, when all measures were combined in a "total retrofit".

Studying the occupant behaviour and how it affects these figures, we have measured the cold and hot tap water consumption separately as well as the energy consumption for laundry driers.

Theoretical calculations of the expected use of energy for space heating, have been carried out with a computer model and the results have been compared to measured data. Good agreements have been achieved with a difference less than approx. 15%, when you also take into account special factors, such as moisture in the external walls, extra shading effects of the windows, changed absorption of solar radiation etc, when implementing additional thermal insulation of external walls and a new surface of sheet metal cassettes.

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INTRODUCTION

The Guldheden Project (BFR 1983, Nilson 1984, 1985a, Nilson et al. 1984) 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 been initiated by the Swedish Council for Building Research (BFR).

The objective was to implement various energy conservation measures (ECM) and, by advanced measurings, 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.

Preliminary results from these projects was also 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 Guldheden Project and some of the final results.

DESCRIPTION OF BUILDINGS

The Guldheden Project consists of nine similar houses, which are situated in Gothenburg, where the annual average outdoor temperature approximately equals +7^{o}C. The hard climate on the Swedish west coast, with driving rain and hard wind, had caused severe damage to the plaster, why the external walls had to be repaired.

Our strategy has been to combine building retrofits with rehabilitation, which is of great importance to have in mind, when evaluating the profitability of the extensive measures in this project.

A short description of the houses 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 $W/m^2,K$. The other houses will be insulated too 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 $W/m^2,K$. New triple glazing in stair enclosures was mainly a consequence of the retrofit of external walls.

The exhaust air heat pumps are used for hot tap water heating as well as for 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 measurements of parameters affecting the energy balance of the buildings have been carried out. For example, the energy consumption for space heating and for tap water heating are measured once a week in each house as well as the energy consumption for laundry driers and the consumption of cold and hot water. Electric consumption for household etc is measured once a year. Temperatures (instantaneous and mean values over time) in apartments and stair enclosure, of exhaust air, inside and on the surface of external walls as well as the outdoor temperature, are measured continously using microcomputers.

Additional measurements 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 savings, the before-after method and, as a complement, the test-reference method (Fracastoro and Lyberg 1983) according to the experimental design plan in Figure 2.

Annual energy consumption for space heating has been calculated using the energy signature technique (Fracastoro and Lyberg 1983, Norlen et al. 1981). Different models for the energy signature have been used to predict the energy consumption for each house before and after retrofits.

We have used simple linear two-parameter models (function of only outdoor temperature or of the difference between indoor and outdoor temperature) as well as more complex models taking also solar radiation into account. Since measuring the energy demand for tap water heating and for laundry driers separately, the energy signatures used, express the energy consumption for space heating at different temperatures or differences between temperatures.

In order to get the total energy consumption for each house (bought energy excl. electricity) the energy demands mentioned above have been added separately.

All models used, have provided good agreements between predicted and measured energy-consumption data for the heating season as a whole. 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 the energy consumption for a house before and after retrofits, it seems that the most simple two-parameter model (function of only the outdoor temperature) would be enough in many cases. However, a two-parameter model that also take into account the indoor temperature, will give us more information of the savings for a specific ECM and the reason for its magnitude.

In carrying out our final evaluation of different combinations of ECM, we have used this two-parameter model as our basic one (Figure 4).

Mainly due to small amounts of solar radiation in Gotheburg during the last heating season, our most complex model has provided no better predictions than the two other models used, studying the entire heating season.

ENERGY SAVINGS

The use of energy after retrofits has been measured for almost three years now. Some preliminary results have been presented earlier (Nilson et al. 1984, 1985a, 1985b).

This final evaluation has been carried out during the end of 1985 and the results from this evaluation will be presented here.

In figure 5 the total consumption of energy will be presented for the different houses. As can be seen from this figure, the levels of the energy consumption before retrofits vary between the houses, mainly due to differences in indoor temperature and air change rate. This has of course affected the energy savings for identical combinations of measures.

The total consumption of energy has decreased from approx. 260 kWh/m^2,year to approx. 225 kWh/m^2,year when only basic measures was implemented (house 3, 8). Implementation of "total retrofit" (house 9) has decreased the consumption of total energy to approx. 145 kWh/m^2,year. The levels of the total consumption of energy after retrofits for the other houses, vary between these two extremes. These figures are based on the area of the apartments including the stair enclosures.

These figures indicate a reduction of the total consumption of energy of approx. 15-45%. Due to differences in occupant behaviour between the before-period and the after-period (hot tap water, laundry driers etc), these effects must be separated before evaluating the energy savings for the different combinations of measures. In order to get a more accurate evaluation, we have used the consumption of energy for space heating instead of the total consumption of energy.

By using the energy signature technique, we have also been able to evaluate the energy savings if the indoor temperature had been +20.5°C in all houses. When we started this project, we thought that this level could be reached without complaints from the tenants. Now we know better! We call this the "normalized" indoor temperature.

These are some of the final results of the energy savings:

- The basic measures have provided savings of approx. 40 kWh/m²,year. The range of variation is 30 kWh/m²,year to approx. 45 kWh/m²,year (Figure 6).
- The combination of basic measures, additional thermal insulation of external walls, conversion of windows to triple glazing and new triple glazing in stair enclosure provided savings of approx. 85 kWh/m²,year (Figure 7).
- The "total retrofit" provided savings of approx. 100 kWh/m²,year, taking into account the reduction of the energy consumption for space heating given by our concept for the exhaust air heat pumps (Figure 8).

Comparing our final results with the preliminary results reported earlier, the levels of the total consumption of energy have decreased somewhat for some of the houses. This is mainly due to some problems with the auxilliary circulation pumps and to less intensified monitoring of the systems than before.

HOT TAP WATER SAVINGS AND ENERGY CONSUMPTION FOR LAUNDRY DRIERS

Looking at the energy consumption for tap water heating and the mean age for the occupants in each house, we found no strong correlation with the mean age but for house 8 (Figure 9). In this house the mean age is lowest but this is also that house where most people are living.

The energy consumption for tap water heating decreased approx. 3% on average for all houses after the implementation of the flow rate regulators during 1982. This decrease is lower than expected, which was 15%. However, the decrease in house 5 is 12% and therefore almost reached the expected level. For house 8, we have an increase of approx. 8% instead. These variations between the houses implies that occupant behaviour affects the water consumption more than technical measures.

No ECM have been implemented for the laundry driers as yet. However, studying the energy consumption for these in different houses, some interesting results are seen concerning occupant behaviour (Figure 10). The two houses in this figure represent the "high-consumer" (house 8) and the "low consumer" (house 5) and the ratio between these two extremes equals approx. 1.5:1. These results lead us also to the conclusion that it is of great importance to measure this kind of energy demands separately, in order to get a more accurate evaluation of ECM.

HEAT PUMPS

The output of the exhaust air heat pumps is approx. 25 kW each. Our concept provides very long operational time, 95-100% of total time during the heating season, which in Gothenburg approx. lasts between September 15 to May 15. For the heating season 1984/85, the operational time varied between approx. 6300 h (house 9) and 6900 h (house 4).

The net average energy savings from the installations of heat pumps was determined to be 35 kWh/m^2,year. The COP was measured to approx. 3.2, considering only the heat pumps, and approx. 2.5, also considering the auxilliary pumps etc.

Studying the outcome for the heating season 1983/84, the results were a little bit better (operational time, net energy savings, etc). The main reasons for this is the problems, mentioned earlier, with the circulation pumps during 1984/85 and that we now have started to leave the maintenance more and more to the houseowner himself.

The difference of operational time between the two installations of heat pumps is, however, not only depending on these factors. Theoretically, the operational time for the heat pump in the house with the "total retrofit" (house 9), will be less than for the heat pump installed in a house with only basic measures implemented (house 4).

Since there still is an overcapacity in the summer, there are discussions on also supplying other houses with hot tap water, heated by the heat pumps. However, this can lead to some conflicts with the district heating company and to less profitability. There is a lot of waste heat in the district heating network in Gothenburg and this leads to low energy prices in the summer, which affects the profitability for the heat pumps.

COMPARISON BETWEEN MEASURED AND CALCULATED ENERGY CONSUMPTION AFTER RETROFITS

Calculations have been carried out for the energy consumption for space heating after retrofits. These calculations have also been compared to measured data.

Our calculations were carried out with the computer model MSA (Nilson 1985b), which in some parts is based upon the BKL-method (Adamson and Källblad 1984). This model uses monthly energy balances as a base for its calculations. 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 11. As can be seen from this figure, it appears that the difference between calculated and measured data for the energy consumption for space heating, is smaller than 10% for most of the houses, except for those houses, where the most extensive measures was implemented (house 1, 5, 9).

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 mainly four factors contribute to this. These factors are:

- The external walls contained a lot of moisture, because of the damages mentioned earlier, and they have not dried out yet. The energy demand for the drying process is taken from the inside, and, because of the construction of the external walls (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 approx. 10 MWh for the first year for a house like this.

- When implementing thermal insulation of the external walls and do not move the old windows to the facade, you get an extra shading of the windows. Calculations have shown that this shading effect accuates the total energy consumption with approx. 10 Mwh/year for these specific houses. Our basic calculations did not take this factor into account.

- Theoretically, the heating season will be shortened when implementing ECM. In reality in Sweden, the houseowners do not always take that 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 told us, this extra energy demand will be approx. 5 MWh/year.

- When changing the old surface of plaster to a surface of sheet metal, the absorption of solar radiation is reduced. This will give an increase of the energy consumption for space heating. To evaluate this amount of energy, calculations have been carried out with a complex computer model. This extra energy demand was calculated to 5-10 MWh/year. Our basic computer model did not take this into account.

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

ECONOMIC PROFITABILITY

The total investment costs for the measures implemented in this project, have reached an amount of about 15 million SEK including design etc. The grants (15%) and loans (85%) have reached about 7 million SEK. The rest has been paid by the houseowner.

Calculations of the cash-flow in present value have been carried out for all the houses, taking also into account the grants and loans, that houseowners in Sweden get from the government for undertakings of energy saving. We have used 15 years as the lifetime for installation measures and 30 years for building measures, a real rate of energy price increase of 2% and a current energy price of 0.25 SEK/kWh.

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

CONCLUSIONS

The Guldheden Project has shown, that large energy savings can be achieved in existing multifamily houses, when extensive ECM are combined. These savings can also be profitable if the implementation of ECM are combined with rehabilitation etc. This conclusion is also the crucial point for the running program of energy conservation in Sweden.

Good aggreement 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 control this very carefully. The project also points to the fact, that all buildings are unique, which is especially important to remember when ECM are planned.

REFERENCES

Adamson, B., and Källblad, K. 1984. "The BKL-method. A simplified method to predict energy consumption in buildings." Document D8:1984. Stockholm: Swedish Council for Building Research (BFR).

BFR. 1983. "Guldhedsprojektet. Energisparkvarter i Göteborg." G16:1983. Stockholm: Swedish Council for Building Research (in Swedish).

BFR. 1985. "Energy use in built environment." Document D1:1985. Stockholm: Swedish Council for Building Research.

Fracastoro, G.V.; and Lyberg M.D. 1983. "Guiding principles concerning design of experiments, instrumentation and measuring techniques." International Energy Agency (IEA) Annex III, Document D11:1983. Stockholm: Swedish Council for Building Research.

Nilson, A. 1984. "Upphandling av energihushållnings- och ROT-åtgärder. Metoder och erfarenheter från Byggforskningsrådets projekt Energisparkvarter." VVS & Energi, Vol 84, No 10, pp. 75-78 (in Swedish).

Nilson, A.; Nordberg, M.; and Walter, A. 1984. "Guldhedsprojektet. Energihushållning på rätt sätt." VVS & Energi, Vol 84, No 11, pp. 44-45, 48-50 (in Swedish)

Nilson, A.; Nordberg, M.; Fischer, M.; and Walter, A. 1986. "Guldhedsprojektet. Energisparkvarter i Göteborg - Energiombyggnad i ett 50-talsområde." Stockholm: Swedish Council for Building Research (final report to be published in Swedish).

Nilson, A.; Nordberg, M.; Fischer, M.; and Walter, A. 1985a. "The Guldheden project. A full-scale study of the effectiveness of energy conservation measures in nine blocks of flats. Proceedings of the CLIMA 2000 World Congress on Heating, Ventilating and Air-Conditioning, Vol 3, pp. 93-98, Copenhagen.

Nilson, A.; Nordberg, M.; Fischer, M.; and Walter, A. 1985b. "The Guldheden project. A full-scale study of the effectiveness of energy conservation measures in nine blocks of flats." Paper presented at the ASHRAE/DOE/BTECC Conference on Thermal Performance of the Exterior Envelopes of Buildings III, December 2-5, 1985, Clearwater Beach, Florida, USA.

Nilson, A. 1985a. "Guldhedsprojektet. Datoriserad mät- och utvärderingsteknik." VVS & Energi, Vol 85, No 1, pp. 36-38, 49 (in Swedish).

Nilson, A. 1985b. "The MSA-method. A computerized model for calculating the potential of energy savings for individual buildings and for the stock of buildings at a national level." Proceedings of the CLIMA 2000 World Congress on Heating, Ventilating and Air-Conditioning, Vol 2, pp. 205-210, Copenhagen.

Norlen, U.; Asplund, L.; and Hjalmarsson, C. 1981. "The enrgy signature of a house." Proceedings of the Energy Audit Workshop, Document D21:1982. Stockholm: Swedish Council for Building Research.

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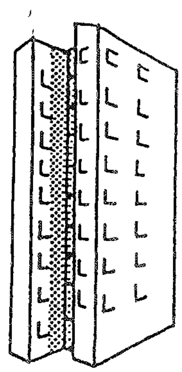


General	o Nine houses built 1952–1953. o Eight to ten storeys. o 332 apartments.
External walls	o Concrete, lightweight concrete as insulation, surface of plaster. o U-value 0,92 $W/m^2,K$
Attic floor	o Concrete, mineral wool. o U-value 0,71 $W/m^2,K$
Windows	o Two pane, linked casement.
Heating	o District 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. Description of building before retrofits

MEASURES \ HOUSE NR	1	2	3	4	5	6	7	8	9	TIME
MEASUREMENTS										Summer 1982
BASIC MEASURES	X	X	X	X	X	X	X	X	X	Spring 1983
MEASUREMENTS										
EXHAUST AIR HEAT PUMP			REFERENCE HOUSE	X				REFERENCE HOUSE	X	Fall/vinter 1983/1984
ADDITIONAL INSULATION OF WALLS	X		REFERENCE HOUSE		X			REFERENCE HOUSE	X	Fall/vinter 1983/1984
CONVERSION OF WINDOW TO TRIPLE GLAZING WITH EXTRA PANE	(X)	(X)	REFERENCE HOUSE				X	REFERENCE HOUSE	X	Fall/vinter 1983/1984
NEW TRIPLE GLAZING IN STAIR ENCLOSURE	X	X	REFERENCE HOUSE	X	X	X		REFERENCE HOUSE	X	Fall/vinter 1983/1984
MEASUREMENTS										Summer 1985

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

Figure 2. Implemented ECM and time schedule

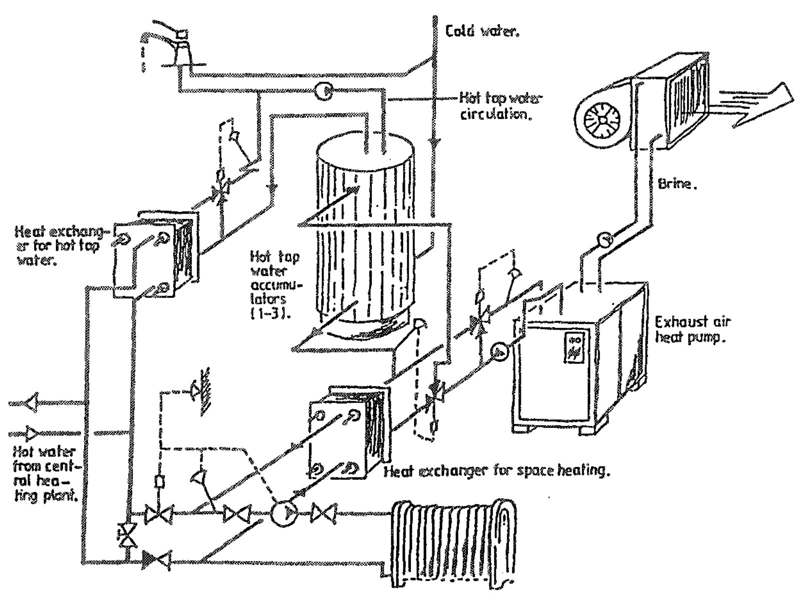


Figure 3. Principle outline of the exhaust air heat pump

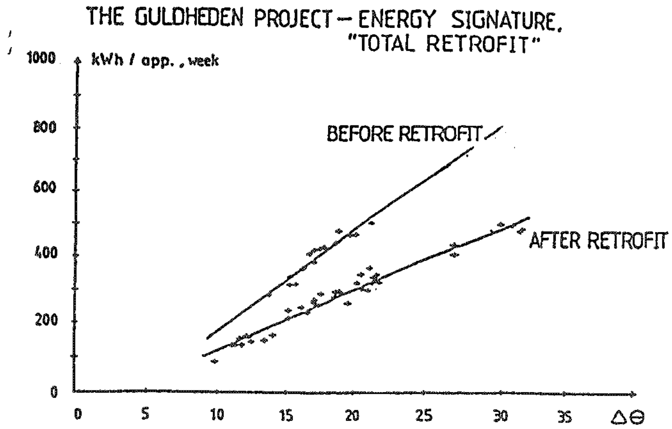
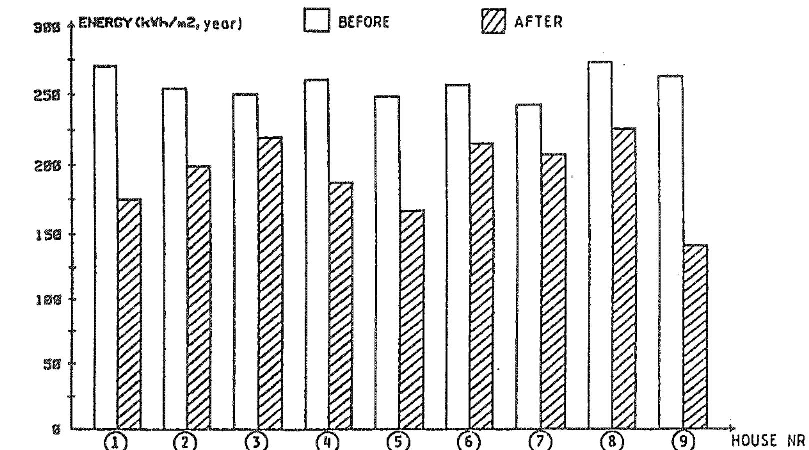


Figure 4. The energy signature for house 9



	1	2	3	4	5	6	7	8	9
BEFORE	270	254	250	260	248	256	242	272	262
AFTER	175	199	220	187	167	215	207	225	142

Figure 5. Total energy consumption before and after retrofits

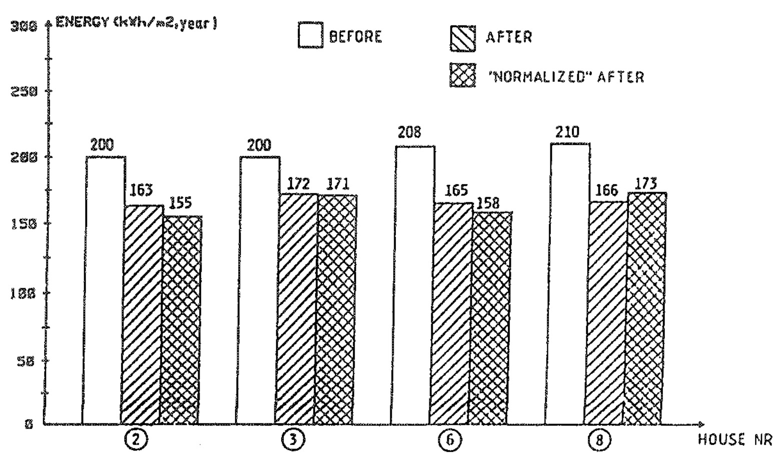


Figure 6. Energy consumption for space heating before and after retrofits

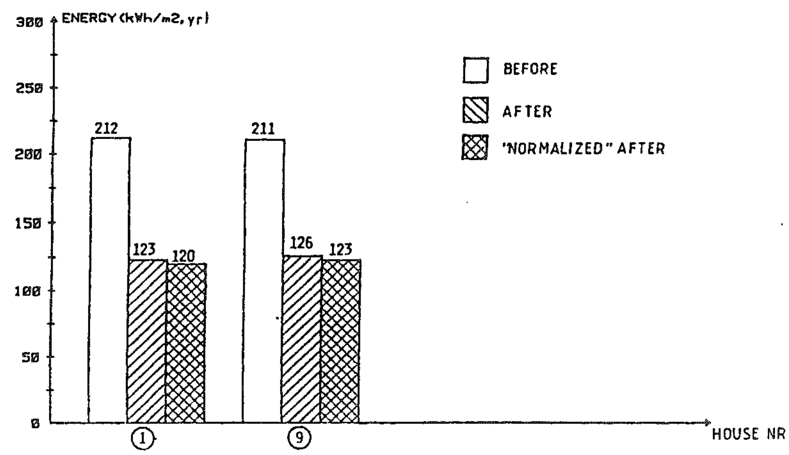


Figure 7. Energy consumption for space heating before and after retrofits

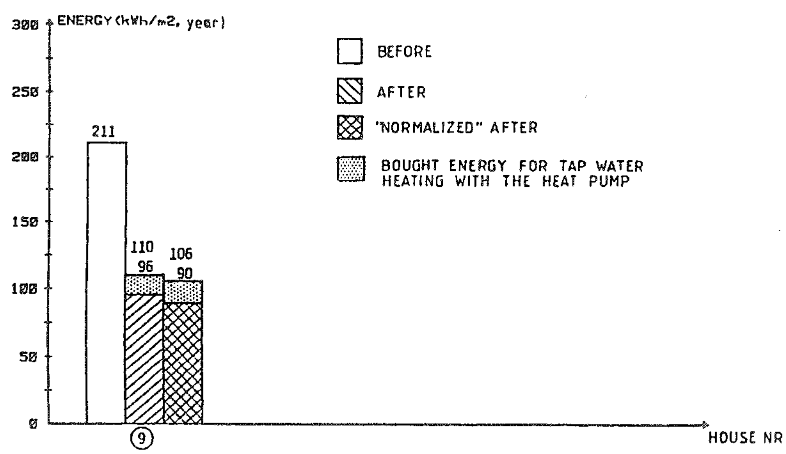


Figure 8. Energy consumption for space heating before and after retrofits

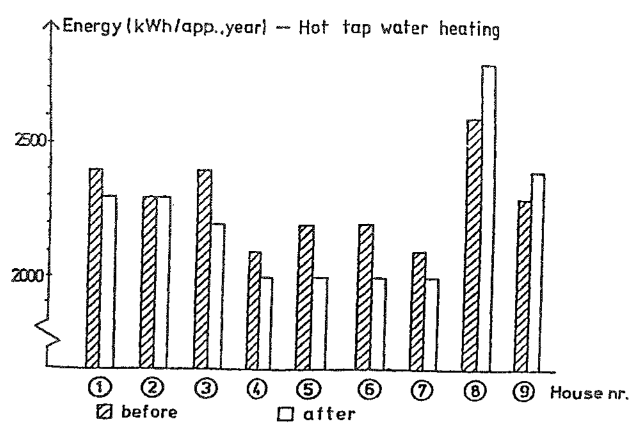


Figure 9. Energy consumption for tap water heating

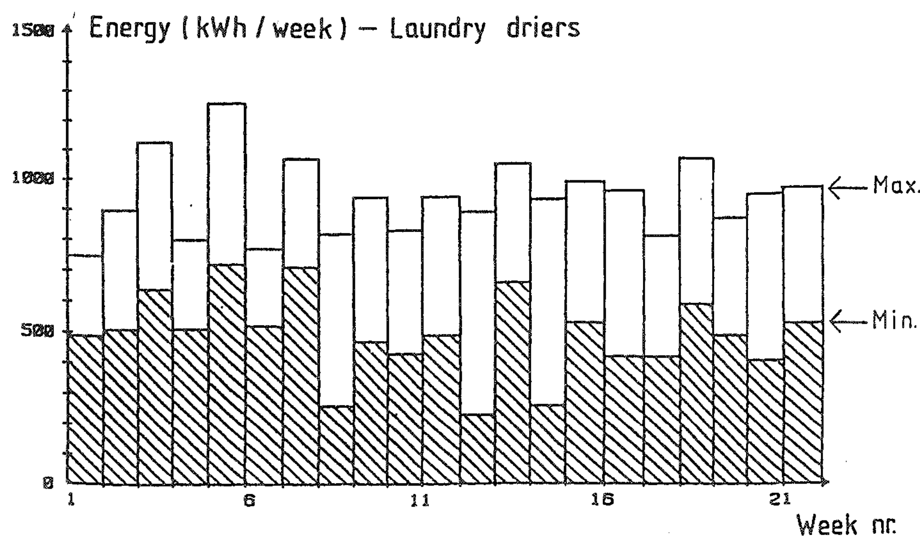


Figure 10. Energy consumption for laundry driers in two houses during spring 1985

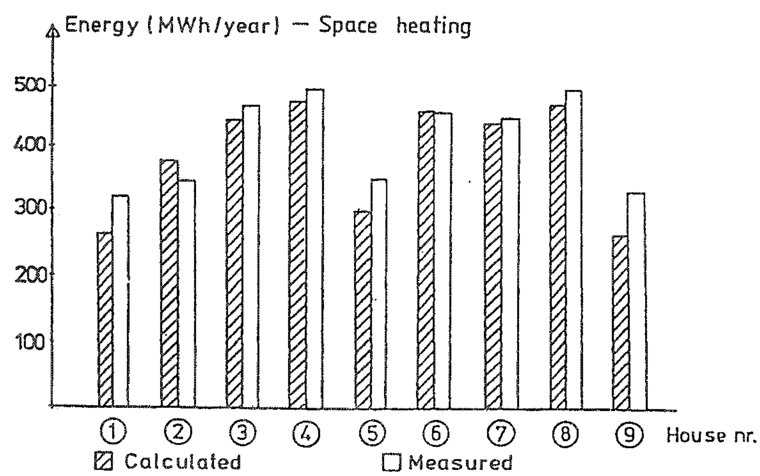


Figure 11. Comparison between calculated and measured data for the energy consumption for space heating after retrofits