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ENERGY-SAVING IN EXISTING BUILDINGS

Ingemar Höglund

There are a number of reasons why we in Sweden are trying to decrease our dependence on oil as a source of energy. The increases in oil prices have, to take but one example, been largely responsible for our heavy budget deficit. Before the oil crisis many of us imagined that we had inexhaustible supplies of cheap and easily accessible energy. Our energy policy had largely been based on the assumption that a constant increase in energy production was essential to economic and social progress (fig 1).

Reviewing measures to upgrade existing buildings in Sweden, the author, who is Professor in the Building Technology Department at the Royal Institute in Stockholm, analyses experience from a number of pilot projects and from studies of selected types of buildings. User response to improvements is an important factor, he suggests, and thus the continued motivation of occupants and owners is vital if theoretical calculations are to be realised in practice. Above all, in order to be both technically and economically sound, energy-saving adaptations in older buildings must be co-ordinated and carried out in a functional sequence.

Etudiant les mesures prises en Suède pour améliorer les bâtiments existants, l'auteur, professeur au département Technologie du Bâtiment de l'Institut Royal de Suède, analyse l'expérience acquise grâce à un certain nombre de projets-pilotes et à des études de types sélectionnés de bâtiment. Selon lui, les réactions des occupants vis-à-vis de ces améliorations jouent un rôle important et la motivation constante des usagers et des propriétaires est vitale si l'on compte réaliser en pratique les calculs théoriques. Si l'on veut qu'elles soient techniquement et économiquement saines, les adaptations permettant d'économiser l'énergie dans les bâtiments anciens doivent surtout être coordonnées et réalisées selon une séquence fonctionnelle.

Fig. 1. Total energy consumption in Sweden (TWh/year), forecast and actual

There is now general agreement on the need to save energy or rather to use energy more efficiently. A key area which offers much room for saving if we are to achieve a relatively quick decrease in consumption is the heating of buildings, both new and existing. The need to save energy in existing buildings is motivated, however, not only by national economic and trade reasons but also to a great extent by private economic and real-estate considerations.

In the seventies the costs of running and maintaining buildings increased drastically. For example, the costs of running and maintaining apartment houses are now as much as 60 per cent of the rent income and thus greater than the capital costs. The

most obvious change is the increase in fuel costs since the energy crisis. Among other running costs maintenance costs are also increasing considerably. Thus fifty per cent of running costs consist of fuel and maintenance costs alone. Energy-saving measures taken in connection with repairs, rebuilding and extensions—a golden opportunity to get the most profitable results from the measures—are thus in many cases financially very well motivated.

SCOPE FOR SAVINGS

In order to decrease the consumption of energy in existing buildings we have to acquire a strictly objective basis for making decisions about energy-saving measures and for carrying them out effectively. Theoretical calculations of the energy needs and potential saving in buildings with regard to profitability requirements have been made primarily by the economy group of the Energy Commission (ref 3), the Ministry of Housing (the Energy-Saving Plan) (ref 5) and by the Delegation for Energy Management (ref 6).

Table 1 is a comparison of the calculated energy-saving potential in buildings by 1990 as the result of building and installation technology, calculated on the one hand by the economy group of the Energy Commission 1977 (see for example figs 2 and 3) based on an average energy price of 10 öre/kWh; and on the other hand by the Delegation for Energy Management 1980 (energy price 15 öre/kWh). The two calculations are surprisingly alike considering that the Delegation for Energy Management based its figures on a higher energy price (and thus a higher potential) but assumed that this potential had decreased compared with 1977 due to saving measures put into effect since.

These theoretical calculations—which indicate a considerable saving potential in buildings—have been checked both by *pilot projects* and by *investigations of statistically selected types of buildings*, before and after the introduction of energy-saving measures. These two types of investigations are both being carried out at present by the Division of Building Technology, the Royal Institute of Technology in Stockholm.

Fig. 2. Profitability chart for saving energy in existing apartment blocks when measures are carried out gradually (gross energy-savings). Source: Energy Commission 1977

Fig. 3. Possible development of energy needs for apartment blocks (gross energy) when measures are carried out rapidly. Source: Energy Commission 1977

Table 1 Energy saving attainable by building technology and installation technology in 1990, TWh gross. (Total energy consumption in buildings was about 170 TWh gross in 1976/77)

Type of building	Energy Commission (1977) 10 öre/kWh	Energy Management Delegation (1980) 15 öre/kWh
Houses.....	13	} 28
Blocks of flats.....	15	
Industrial buildings.....	5	
Others.....	18	15
Total	51	48

Corresponding savings according to Energy Commission in 1990 in the industrial sector = $\approx 8 - 18$ TWh
transport = $\approx 3 - 14$ TWh
other = $\approx 5 - 6$ TWh

The seminal pilot project described in the article, old apartment blocks at Ulvsunda, Stockholm, before and after improvement.

PILOT PROJECTS

In several pilot projects the steps taken are analysed and followed up systematically and the energy consumption of significant target groups is measured over a long period of time. The results from such a pilot project are summarised in ref 4, where the results are shown of energy-saving measures in an old area of narrow apartment blocks containing about 100 flats in Stockholm (Ulvsunda). This type of building is an important target group. In the Stockholm region alone there are about 45 000 flats in buildings of this type built between 1934 and 1952. In this area heat is supplied from a central boiler plant heated by oil. The results are from a test period of three years. A second test period is now in progress.

The object was to determine the energy consumption in old buildings by calculation and measurement and to analyse the effect and profitability of technical improvements to the buildings

and installations. Another important object was to prove in practice that it is possible to save energy by fairly simple measures, which may hold down rent increases and improve the indoor climate. This possibility was not generally accepted when we planned our investigations shortly after the energy crisis.

The consumption of oil was high at the starting point, about 60 litres/m². The reasons for this were an unfavourable form factor (eg shape of apartment block), low thermal resistance in walls and roofs, draughty windows and doors and deficiencies in the heating system, such as uneven distribution of heat between the different floors. These defects were 'masked' by high average room temperatures, which increased oil consumption even further.

After the first stage consumption had been reduced by half. Theory and practice were in beautiful agreement. The final level of consumption, after measurements made in stage 2, is reckoned to be the same as for corresponding new building areas.

Preliminary investigations for the project included interviewing people living in the area. Among other things they showed that the tenants reacted very differently to the indoor climate. Thirty per cent of them thought that the temperature was satisfactory, 10 per cent thought that it was too hot and 52 per cent thought that it was too cold part of the time; 21 per cent aired the rooms because it was too warm and 27 per cent used the gas stove as an extra source of heat when it was cold. The heating system was badly adjusted. The tenants were also disturbed by noise from Bromma Airport and nearby thoroughfares.

The investigations also showed that 69 per cent of the tenants were disturbed by draughts, mainly from windows and front doors. All the above-mentioned defects have been eliminated by various measures.

STUDYING SELECTED GROUPS OF BUILDINGS

The object of this investigation (ref 1) has mainly been to evaluate the real effects of energy-saving measures by randomly choosing a large number of buildings where such measures have been taken. In all 1144 buildings have been inspected, 944 houses and 200 blocks of flats. The examinations have been carried out in five regions: Norrbotten, Västerbotten, Stockholm, Gothenburg-Bohus and Malmöhus.

The measures or combinations of measures that have been studied in the investigations have been chosen because they have, up to now, accounted for a great deal of the Government grants and have been very widely adopted.

Investigated measures for single-family houses:

- supplementary insulation of outer walls,
- supplementary insulation of attic floor constructions,
- supplementary insulation of outer walls and attic floors,
- supplementary insulation of attic floors and installation of radiator thermostat valves,
- installation of thermostat valves and automatic shunt valves,
- installation of triple-glazing or supplementary glazing,
- supplementary insulation of outer walls and installation of triple-glazing or supplementary glazing.

Saving litre oil/flat, year

Fig. 4. Average measured energy saving for attic floor insulation + thermostat valves, with confidence limits (hatched area) and average theoretical savings (arrows). (Ref. 1)

Investigated measures for blocks of flats:

- supplementary insulation of outer walls,
- supplementary insulation of attic floor constructions,
- installation of radiator thermostat valves,
- installation of radiator equipment.

The basis for the calculation of the energy-saving includes technical data of the various buildings and data of actual energy consumption before and after carrying out a particular measure. Measured saving is the annual energy-saving that can be calculated for the buildings where action has been taken, provided climate conditions have been normal for the district.

The statistical uncertainty for the measured saving effect is given by confidence limits for each group of measures and region. The confidence limits have been constructed by means of average values, standard deviations from measured energy-saving and data about the number of buildings in the group in question. The probability that a confidence limit covers the average saving effect for all the buildings in the population is about 95 per cent.

As an example of interim results, figure 4 shows a comparison between theoretical and measured saving and variations in measured savings in the buildings where action has been taken, with regard to the combination of attic floor insulation/thermostat valves in houses.

As can be seen, the results show good energy saving for the investigated combination of measures. Even if the variation in energy saving is large, the main result is that the saving by supplementary insulation of the attic floor construction is greater in practice than in theory. It is also considerably larger than if attic floor insulation was the only measure carried out.

The main results of the total investigation can, in somewhat simplified form, be summarised as showing that the average values of the actual saving in practice are approximately the same as the theoretically calculated values, but that the results show a wide standard deviation. In many buildings considerably better saving has been obtained in practice than was calculated theoretically. On the other hand the saving in other buildings has been substantially smaller and in some cases even non-existent. These extreme cases are now being examined individually. In this way we reckon to obtain useful supplementary results, not least for the men on the job.

SOME PRACTICAL IMPLICATIONS

1. To obtain the best effect regarding both *lasting energy saving* and a *good indoor climate* technical measures applied to building and installations have to be co-ordinated and appropriate strategies or combinations of measures have to be taken according to the various functions and energy status of the buildings (fig 5). Experience shows, for example, that an appropriate strategy for some interacting measures is that they should be carried out in the following order:
 - (I) Supplementary insulation/draught exclusion/converting double-glazing into triple-glazing.
 - (II) Adjustment of heating system/ventilation system.
 - (III) Lowering of temperature.

Fig. 5. Interaction between climate factors, building technology, installation technology and people (presented here very schematically) really determines energy consumption in a building. It is thus a question of optimising a complicated thermal dynamic system.

2. If the heating requirements of a building are reduced by technical measures which affect the building itself, the heating plant must be adapted to the new lower heating requirements of the building (fig 6).
3. Technical measures result in a higher, directed, operational temperature which makes it possible to have a lower room temperature, so that when the temperature is lowered the indoor climate is maintained or even improved, (fig 7 and 8).
4. A reduction of the temperature in a building with a poorly adjusted heating system does not lead to a permanent reduction and saving of energy. The difference between the coldest and the warmest flats will be too large; the tenants in the coldest flats will complain (fig 9).
5. Thus, reductions of temperature—even in combination with careful adjustments of the heating system—do not necessarily lead to any permanent reductions if technical deficiencies in the building, in the form of a low degree of heat insulation, are 'masked' by the high average temperature of the room air. Tenants will not accept the lower degree of comfort (except when we are in a critical energy supply situation).
6. The results also show that technical measures which affect a building should often be followed by adjusting/regulating the heating system. Otherwise there is a risk that the result will be a rise in the temperature of the air in the room and not all the energy saving aimed at will be realised.

Fig. 6. If the heating system is not adapted to the new load when a building's heat requirements are reduced, there is a risk of loss of efficiency ($\Delta\eta$). Modifying the system (eg changing the boiler and burner, or possibly switching to electricity for water heating/space heating), should be considered

Fig. 7. Level of floor comfort as a function of air and floor temperature. If the floor surface temperature in a room is too low, the lack of comfort may make it impossible to lower the air temperature

Percentage of flats

Fig. 8. Calculation of possible lowering of air temperature with maintained operative temperature (θ_{op}). The figure refers to supplementary insulation of an outer wall in one of the buildings in the Ulvsunda project. The operative temperature was set at 21 °C. Example: In order to maintain the directed operative temperature at 21 °C with a temperature difference indoors-outdoors of $\Delta\theta$ 30 °C, the required air temperature is $\theta_{ia} = 22.5$ °C for the original wall construction. With a supplementary insulation of about 4 cm of mineral wool ($R_1 = 1.0$) the air temperature can be lowered to approximately $\theta_{ia} = 21.7$ °C without the operative temperature becoming lower. By supplementary insulation (and draught exclusion) the surface temperature of a building's inner walls is thus increased and the air temperature can be lowered accordingly. This can very often be done with a resultant improved indoor climate. It should, however, be noted that the heating system usually has to be adjusted first. Otherwise there is a risk of complaint from the tenants in the coldest flats

Fig. 9. On left an imperfectly adjusted heating system; on right, a carefully adjusted system.

This schematic diagram shows temperature distribution before (continuous line) and after (broken line) a reduction of temperature in a building with an imperfectly adjusted heating system. (Vertical axis: Percentage of flats with temperature < θ_a). 20 °C is reckoned to be the lower limit for complaints. In the first-mentioned case a permanently lowered temperature is not achieved. Due to complaints from the tenants in the cold flats the temperature is usually increased again. In order to achieve a permanent decrease the heating system has to be adjusted first

7. When putting in draught excluders the type of ventilation system must be considered. Especially in buildings with natural ventilation a change to new weather-stripping for windows and doors (tubular or V-shaped, made of neoprene or EPDM-materials) is an effective measure, for example.
8. Living habits, the know-how of the tenants and of the operating staff, interest and motivation affect energy consumption and energy-saving substantially.
9. Technical measures such as thermal insulation and converting from double-glazing to triple-glazing are relatively expensive measures; but they have a long life-time and good reliability and *they lower the need for heat considerably*.
10. Many technical installation measures are relatively inexpensive. However, improved boiler operation, for example, requires continuous follow-up. There is no saving effect if there is a return to the old ways. Reliability and length of life are thus lower. Thanks to these technical installation measures, however, great savings have been achieved when over-dimensioned equipment with a poor level of operation and maintenance could be rectified.
11. Profitability, amount of energy-saving, availability of technology, degree of reliability and a building's function and energy status are among the important factors in determining strategies in the battle for energy-saving.
12. Depending on the building concerned, the 'rebuild-save energy' measures can vary quite considerably. For example, in the case of a house with electric heating technical building measures may take pride of place, whereas in a large factory building adjustments of heating, water and sanitation to lower energy consumption in processes and ventilation should be given priority.
13. Historic buildings should, of course, be rebuilt with care and caution. Exterior supplementary insulation is not usually suitable, not even when the facades of buildings from the turn of the century need renovating. These buildings often have heavy facade mouldings and complicated window-frame decorations. These decorative features are usually only found on the street facades while the walls facing the inner courtyard are often smooth. It might be possible to increase the insulation only on the walls facing the inner courtyard and renovate the street facades in the usual manner without supplementary insulation, or simply increase the internal insulation. Buildings from the turn of the century are usually found in the central parts of a town and are relatively deep, are terraced and have large windows. The area of the outer walls amounts to half or less than half of the floor space; thus the energy losses through the outer walls are a relatively small part of the total energy consumption.
14. Within the housing sector there is still a great need for professional information about energy-saving measures. It is not only a question of working out what savings can be achieved; it is also important to spread information about how the measures should be planned, optimised and carried out, or to whom to turn to get the measures carried out. In order to achieve important and permanent savings better training at all levels is required. It is then necessary to inform all those who are involved with planning, executing, checking and operating economy measures.
15. Even if many measures are financially very profitable, they will not always be carried out unless the state also provides information, training and guidance. A basic need if good results are to be achieved is increased support for research and development (without a top-heavy bureaucratic organisation), which will make better energy economy possible. This is especially true of research and development of new technology.
16. If private investment for energy economy is to be facilitated, it is of great importance that the terms of loans are easy to understand. The procedure for granting loans will also have to be simplified so that complications in the financial transactions do not prevent badly needed economy measures from being realised.
17. The building sector has discussed, for example, whether regulations requiring the obligatory adjustment of boilers and of heating systems should be introduced. Regulations and restrictions can also be used to prevent unwise investments being made in rebuilding projects. For instance, regulations may forbid renovating a facade without having first investigated the possibility of improving the insulation at the same time. In the same way it may be worth considering whether triple-glazing or similar insulating construction should be prescribed for an old building where the window frame has to be replaced in any event because of age. In both cases, however, the costs of an energy-saving measure should not in principle exceed the additional cost of the improved level of insulation.
18. The terms of loans as well as the way the rent is calculated must also be designed to the advantage of all the parties concerned, for example both landlords and tenants. Out-of-date regulations governing the way in which rent is calculated and which do not stipulate energy economy, or which even discourage energy-saving, should be revised.

CONCLUSION

Even though Sweden is a leading country (see fig 10) when it comes to energy-saving building construction, and even though our economy measures are gradually beginning to pay off (the total energy saving today is about 7-10 TWh/year), I do not think that what we have achieved so far gives cause for self-congratulation. We have hardly got beyond 'the end of the beginning'.

If we are to succeed, it is necessary for the whole building sector to play its part. The building sector, however, is unfortunately a rather slow-moving machine. We must not forget its complicated decision-making structure and the large number of parties that are involved in the building and management of property. A pre-requisite for our extensive economy program is that a great number of people with different functions, backgrounds, qualifications and opportunities each make their contributions. Administrative measures are all well and good — but they are not enough!

Fig. 10. Sweden has long been a leading country in energy saving in buildings. The diagram shows how energy consumption has been lowered for a newly-built standard flat of about 70 m² from 1950 to 1980 (data from HSB properties). The diagram also gives an idea of the distribution of various heat losses and how they have been decreased over the years

The individual's personal initiative is vital and has often been a very strong driving force that has produced splendid results. I should like to close this report by raising my hat to Mr Nils Göte Håkansson (ref 2), a retired engineer in Ludvika in Central Sweden. Thanks to his enthusiasm his tenant-owners' association of two-storeyed terraced houses has with very moderate investment managed to bring down oil consumption in 1980 to about 16 litres/m² heated net dwelling area (this figure covers heating, hot water and laundry and is adjusted in accordance with the local thermal index (fig 11). He also points out that, according to his calculations, savings in the region of another 20 per cent are quite feasible.

Annual consumption, m³

Fig. 11. Fuel consumption 1949-1980. There are no figures of consumption available for the years 1946-48, but it was probably high. The values in the diagram are not adjusted in accordance with the thermal index. Up to and including 1953 no adjustment was made for the fuel in stock at the beginning and end of the year. The diagram also shows that the first serious attempts to save energy were made during the early fifties.

1. During the years 1946-53 the fuel was coal, coke and wood.
2. From 1953-56 coal and oil.
3. After 1956 exclusively oil.
4. The figure for 1953 is not fully reliable.

The average figure for 1957-59 is about 62.4 m³ per year; for 1960-69 it is about 71.6 m³ per year. In 1970 more intensive energy-saving measures were introduced, which gave satisfactory results. This is also obvious from the diagram.

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