Conclusions

1. The original roof membrane (now acting as a vapour barrier) should be airtight.
2. The additional insulation should be at least 100 mm thick and in any case at least as thick as the original insulation.
3. The cavity ventilation should be kept open a year to dry out before it is closed.

Further it must be admitted that a leak in the new roof membrane will be serious since it may last long before it is discovered. In order to reduce (but not totally eliminate) the risk of rain-water collecting in the new insulation material (mineralwool or foam plastic) as a result of even a small leak in the top membrane it is strongly recommended to use a slope of not less than 1:40 on the new membrane surface.

The fuel oil saved with the additional insulation will per m^2 be

$$E = \frac{\Delta U \cdot D \cdot 24}{\eta \cdot B \cdot 1000} \text{ l fuel oil/per year}$$

where
ΔU = change in U-value $W/m^2\ {}^oC$
D = degree days (in Denmark 3000)
η = efficiency of oil burning equipment
B = the kWh in 1 l of fuel oil.

For Danish conditions the energy saving will be

$$E = \frac{\Delta U \cdot 3000 \cdot 24}{0,8 \cdot 10 \cdot 1000}$$

$$E \approx 10 \cdot \Delta U \text{ l fuel oil/per year.}$$

This formula is of course general applicable and not especially connected to additional insulation of flat roofs.

#924

Estimating Effects of Energy Conservation Measures: A Swedish Study

URBAN NORLÉN and MARGARETA HOLGERSSON

The National Swedish Institute for Building Research
Box 785, S-801 29 GÄVLE, SWEDEN

Summary

This paper concerns the problem of estimating expected effects of energy conservation measures. As regards retrofit insulation, there has been a consensus about the way of estimating expected effects. A well-known principle for calculating the effects from e.g. insulation of outer walls has been to consider the effects proportional to the area insulated, the decrease in U-value and the number of degree-hours. This principle was used, for example, when the Swedish Energy Conservation Programmes were worked out in 1975 and 1978.

However, in the light of the Swedish Energy Saving Survey of 1980, a re-valuation of established methods for calculation of expected effects is called for. In this paper we will present some results from the survey supporting this point of view.

The survey produced two kinds of estimates on the effects of a number of energy conservation measures:

a) theoretical estimates based on the principle described above (the simple degree-days model)
b) empirical estimates based on the amount of savings actually obtained in a house after an energy conservation measure was carried out.

A comparison is made of the two methods of estimation, where the limitations of the theoretical estimates are revealed. The implications of the results are also demonstrated.

1. Introduction

In the Swedish Energy Programme, a great emphasis is put on actions concerning existing buildings. This is quite natural, since nearly half of the total energy consumption in Sweden is spent on space heating, domestic hot water and electricity. An Energy Conservation Plan for existing buildings was passed in a Government Bill 1978. The goal stated in this Bill is to achieve a gross energy saving of 25-30 % of the total energy consumption in existing buildings within a period of 10 years.

During the preparation of this and earlier plans, little was actually known about energy conservation potentials in general - for example the technical qualities of existing buildings and the effectiveness of retrofit insulation and other energy conservation measures. Predictions for future energy savings were all based on purely theoretical considerations.

It was therefore considered necessary to review the plan after three years, on the basis of evaluation studies. To obtain empirical information about the effects from different energy conservation measures, a large-scale statistical sample survey was carried out in Sweden during the years 1979-80, c.f. [1]. This 1980 Energy Saving Survey was promoted and funded by the Swedish Ministry of Housing and Physical Planning. It comprised about 1000 houses - both single-family houses and apartment blocks - randomly sampled from five different Swedish regions. The houses had been subjected to different energy conservation measures during the years 1975-78.

Data from this survey consist of technical information about the houses and about the different energy conservation measures performed. Further, energy consumption data for the periods before and after the measure was performed were collected in retrospect for each house. To estimate the effects from specific measures, a mathematical model was formulated. In addition to these empirical estimates, theoretical estimates were calculated.

The survey revealed considerable discrepances between empirically and theoretically obtained savings effects of retrofit insulation measures. These discrepancies will be demonstrated and discussed below.

2. Two methods for estimating the effects of an energy conservation measure

Consider the "anomalous" result from the survey illustrated in fig 1. This figure shows two sets of estimates of the savings effect (in litres of oil per annum) of different retrofit insulation measures carried out in 341 houses. The two sets of estimates are obviously to some extent in conflict with each other:

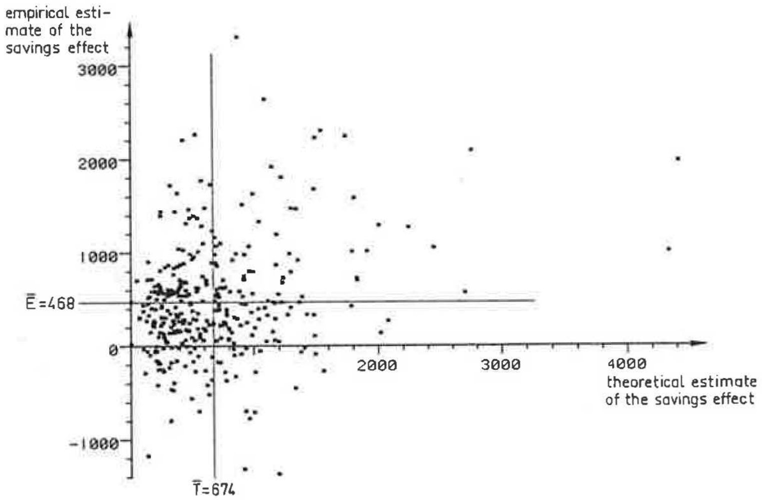

Fig 1. Empirical and theoretical estimates of annual energy savings effects in 341 retrofitted one-family houses from the Swedish 1980 Survey (in litres of oil)

We make the following observations:

1. The empirical estimate varies considerably between the houses (s_E=602) and so does the theoretical estimate (s_T= 539)
2. The empirical and the theoretical estimates vary considerably between themselves (r=0.26)
3. The average empirical and theoretical estimates differ ($\bar{E}$=468 and $\bar{T}$=674)

What are the reasons for these confusing results and what conclusions should be drawn? In this paper we will try to give som answers. We start by describing the two methods used to estimate savings effects.

Both methods rely on data collected in the survey. To characterize the two methods, we divide the survey data into three categories:

A. Technical information about the building and about the energy conservation measure performed, e.g., facade areas and U-values before and after the retrofit.
B. Energy consumption data from periods of time before and after, respectively, the retrofit.
C. Temperature data consisting of outdoor temperatures.

The empirical estimates are based on data of type B and type C. The savings effect of a measure in a specific house is obtained by a comparison of the amount of energy consumed before and after the retrofit was made. Briefly, the estimate can be characterized as the difference between:

- the average amount of energy consumed per degree-hour during a period of time before the retrofit was made

and

- the average amount of energy consumed per degree-hour during a period of time after the retrofit was made

multiplied by

- the number of degree-hours during an "average year"[1].

The theoretical estimates were based on a combination of data of type A and type C. The savings effect was estimated simply by multiplying together

- the decrease in thermal conductivity of the building component in question (= a measure of the improvement of the thermal properties of the building),
- the retrofitted area of the building envelope,
- the number of degree-hours during an average year

and

1) The number of degree-hours for a specific period of time is obtained as the sum of the indoor-outdoor temperature differences over the hours within the period which are in the months November -March and over the hours which are in other months provided that the outdoor temperature was below certain critical levels in the interval 10-13°C. The critical outdoor temperatures were: 12°C, 10°C, 11°C, 12°C and 13°C during the months April, May-July, August, September and October, respectively. Only monthly average temperature data were available. To obtain hourly outdoor temperatures linear interpolation between the monthly figures was employed. The number of degree-hours for an "average year" is calculated on basis of outdoor temperature data during the period 1972-79 in Sweden.

- the inverted value of the efficiency of the heating system.

It should be noted that no energy consumption data are used in the application of this last method. Instead, it rests on a rather well-founded theory of the heat flow through a building and of how this heat flow is changed by retrofit insulation of outer walls and/or attic. In using this method, a number of simplifying assumptions have to be made.

For a detailed presentation of the methods and a discussion of the possibilities of generalizing the survey results, see [2].

3. Comparison of the two estimation methods

The savings effect of a retrofit insulation may be defined as the change of energy consumption in a house which occurs when the measure is carried out and which would not occur if the measure had not been carried out. Thus, it can never be measured directly. The notion of the effect of an energy conservation measure must therefore of necessity be a hypothetical construct.

Furthermore, we can never be sure that factors other than the energy conservation measure itself do not affect the energy consumption in a house and thereby the obtained estimates in a systematic way. To the difficulties already mentioned we may add the problem of collecting reliable data with acceptable measurement errors.

In the present survey, a number of additional influences were identified:
- In some houses, after or in connection with the energy conservation measure being carried out, other changes may have occured, such as:
  - the household structure changed
  - the house was rebuilt
  - the oil burner was replaced
  - the behaviour of the residents changed systematically.
- The outdoor climate after the retrofit may have been different from the outdoor climate before the retrofit.
- The indoor temperature may have changed after the retrofit. In some houses the temperature may have been raised, to provide increased thermal comfort. In other houses, the temperature may have been lowered.

Two kinds of strategies were applied to take the above into account, viz.
- the level of the disturbing factor was kept constant, or
- the effect of the disturbing factor was eliminated.

As an example of the first solution, we can mention that only those one-family houses where the same household had occupied the dwelling during the entire period of investigation were permitted to participate in the survey. The rest of the one-family houses were discarded from the investigation. By doing so we expect to diminish the effect of differences between behaviour of households which would influence the consumption of energy in a systematic way. An example of the second solution is the correction employed for different average outdoor temperatures in the periods of time before and after the retrofit.

As we did not have any information about the indoor temperatures of the houses, possible changes in connection with the measure

being carried out could not be taken into account in the same way as changes in outdoor temperatures. As a consequence of this we chose to include in the savings effect of a specific measure, also the effect of a possible change of indoor temperature. This interpretation of the effect corresponds to the change in energy consumption actually obtained by carrying out the measure.

The principal aim of the survey was to estimate the average savings effects of energy conservation measures in large populations of buildings. Such averages were presented in the form of confidence intervals, as illustrated by figure 2.

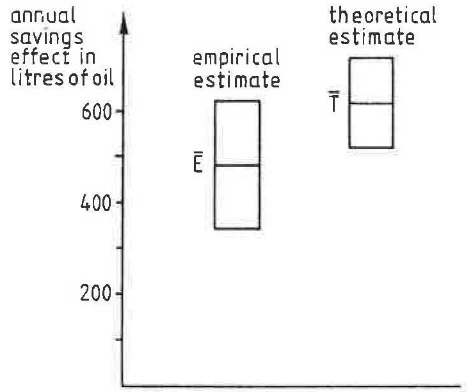

Fig 2. Confidence intervals (95 %) for the average annual energy savings effect of retrofit insulation of external walls in the Gothenburg region (in litres of oil). The box to the left represents a confidence interval based on empirical estimates. The box to the right represents a confidence interval based on theoretical estimates

To reveal possible remaining influence on estimated average savings effects of disturbing factors not properly taken into account or perhaps not even considered, a number of analyses has been carried out. By a thorough sensitivity analysis the impact of a large number of corrective actions to eliminate undesirable effects were studied. This sensitivity analysis was employed for the empirical as well as for the theoretical estimates. Furthermore, a time-series analysis was made with the purpose of discovering slow trends in the development of the energy consumption pattern in houses investigated during the 1970's. A trend that is not taken into account might greatly influence the empirical estimates.

The sensitivity analysis gave the following results:
- The empirical estimates of average savings effects are rather insensitive to variations in the corrections performed to eliminate the influence of disturbing factors. Moreover, the time--series analysis did not reveal any underlying influence of factors unrelated to the point of time at which the retrofit took place.
- The theoretical estimates of average savings effects are sensitive to the simplifying assumptions and qualifications that were made.

To sum up, the empirical estimates were confirmed by the sensitivity analysis, whereas relying on the theoretical estimates appears to be a risky undertaking. This result explains to some extent the differences between the averages shown in figure 2.

The accuracy of estimates of savings effects obtained in individual houses has not been studied. It can be assumed that these estimates are subject to relatively large errors. For one thing, the influence of random factors disturbing the estimate are not cancelled out in the individual case as they tend to be when individual savings effects are averaged. The large variation between the two sets of estimates shown in figure 1 provides ample evidence of individual variation.

4. Discussion

We may now return to the observations made above by inspection of figure 1.

O b s e r v a t i o n 1. A large variation in estimated savings effects between houses.

The large variation in estimated savings effects between houses - regardless of which method for estimation we consider - evidences the need to perform large statistical surveys involving many investigated houses if the purpose is to estimate average effects with sufficient accuracy.

This large variation also confirms that isolated empirical findings based on a few subjectively selected houses are of little practical value when energy conservation programmes are prepared, supposedly on the basis of expected average outcomes.

In the large variation is embedded a promising opportunity for the design of efficient energy conservation programmes. That is, if suitable means can be created for directing the measures to those houses where large energy savings effects can be obtained. Using data from the Swedish 1980 Survey, we will illustrate this fact.

Consider the following three variables:
1. Empirical estimate of the savings effect (per annum)
2. Energy consumption in the house before retrofit (per annum)
3. Theoretical estimate of the savings effect (per annum)

First, let us reorder the 341 retrofitted houses in the sample in descending order with respect to the first variable "Empirical estimate of the savings effect", so that the first house has the largest (empirically) estimated savings effect of the sample, the second house has the second largest etc. After that, calculate successive averages of the empirical estimates of the savings effects, starting with the average of the first two houses, continuing with the average of the first three houses and so on until the whole sample is included. The average over the whole sample is still equal to 468. If we plot these averages against the corresponding percentage of the sample, we get the upper curve in figure 3.

Secondly, we reorder the 341 houses in the sample according to the second variable "Energy consumption in the house before retrofit". Again, we calculate successive averages of the empirical savings effects in the manner described above. The result is the middle curve in figure 3.

Thirdly, we reorder the houses according to the third variable "Theoretical estimate of the savings effect". After again having calculated successive averages of the empirical savings effects, we obtain the lower curve of figure 3.

From figure 3 we may draw the following conclusions. If we were able to select the 25 % of the houses with the largest empirical savings effects we would increase the annual average savings effect from 468 litres of oil to some 1200 litres of oil.

In fact, such a selection of houses is impossible to carry out in practice. It is, however, possible to use the "second best" solution. We can select, say the 25 % of the houses which have the largest energy consumption. Inspection of figure 3 shows that the average savings effect would then be some 900 litres of oil for these houses. That is, we would almost double the average savings effect of the retrofits. (If we, however, continue to include additional houses, the average savings effect will be diminished.) The corresponding average if we had selected the 25 % of the houses based on a ranking after the theoretical estimates is considerably lower, or some 600 litres of oil.

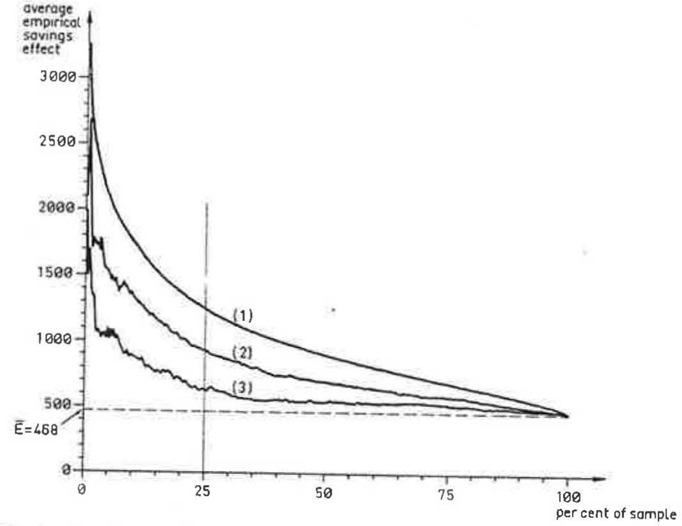

Fig 3. Empirical estimates of the average annual energy savings effect (in litres of oil) for different percentages of a sample of 341 retrofitted houses from the Swedish 1980 Survey. The houses are reordered in descending order according to:
(1) Empirical savings effect
(2) Energy consumption in the house before retrofit
(3) Theoretical savings effect

O b s e r v a t i o n 2. Large differences between empirical and theoretical estimates of the savings effect for single houses.

In retrospect, it is not strange that empirical and theoretical estimates differ between houses. One explanation of this difference has already been mentioned: In the empirical estimates any possible change in the indoor temperature in connection with the measure being carried out is included. This is, however, not the case for the theoretical estimates.

The large differences between empirical and theoretical estimates imply that the latter are of a limited value in connection with recommendations to house owners concerning what measures are worth carrying out in their own houses and how much energy they are likely to save by a retrofit.

Consequently, there is an urgent need to develop more satisfying indicators to predict how much energy that will be saved than the theoretical estimates discussed in this paper. For example, we may use the fact that the conservation effect obtained by a retrofit is much stronger correlated with the energy consumption before the retrofit than with the theoretical estimate. In our sample of 341 houses, the correlation between the empirical estimate and the energy consumed before the retrofit is 0.56, whereas the correlation between empirical and theoretical estimates is 0.26.

While waiting for better indicators of what can be saved by retrofit measures in a specific house, house owners should be informed that every prediction about what savings to expect is subject to large errors and uncertainty.

O b s e r v a t i o n 3. The average empirical and theoretical estimates of the savings effects differ.

In the sample of 341 retrofitted houses, the average empirical savings effect ($\bar{E}$=468) is only about 70 % of the average theoretical savings effect ($\bar{T}$=674). If we, however, consider the different types of retrofit measures performed in the survey separately, we find a better agreement between averages for single measures than between averages for combined measures. This can be seen in the table below.

Retrofit insulation of	No. of houses	Average empirical estimate	Average theoretical estimate	Quotient
External walls	130	499	564	0.88
Attic	106	435	492	0.88
External walls and attic	105	463	994	0.47
Total	341	468	674	0.69

The agreement between empirical and theoretical averages as regards retrofit insulation of walls and attic, separately, may suggest that theoretical averages should suffice as a basis when, e.g. national energy conservation programmes are prepared. However, the empirical findings concerning the combination of the two measures indicate that a certain cautiousness should be used.

References

[1] Swedish Ministry of Housing and Physical Planning, "Effects of energy conservation measures in dwellings where governmental subsidies were granted" /In Swedish/, Stockholm, 1980

[2] U Norlén, G Anderlind, L Asplund, C Hjalmarsson, M Holgersson and J Nordlander, "Estimating the effects of energy conservation measures". Technical report from the Swedish survey 1980 of energy savings in retrofitted buildings (in preparation), Gävle, 1981

Energy Saving in Existing Residential Buildings

Arne Elmroth, Jan Forslund, Conny Rolén

Division of Building Technology
The Royal Institute of Technology, Stockholm, Sweden

Background, purpose and aims

Since 1974, the Authorities in Sweden have provided considerable economic support in the form of loans and grants for energy-saving measures in existing buildings. The purpose of this support is to stimulate the more effective use of energy and improved energy management when heating buildings.

In the Spring of 1978 the Swedish Parliament passed an Energy Conservation Plan for existing buildings.

The aim of energy savings is to reduce the gross annual energy usage for heating buildings and premises in Sweden by 39-48 TWh over the ten-year period from 1978-1988. This corresponds to a reduction in energy consumption of 25-30% in existing buildings.

Several different investigations formed the basis for the Energy Conservation Plan and the evaluation of the same. Essentially, these were of two types - substantial theoretical calculations of potential energy saving from different measures carried out and the evaluation of energy-saving effects studied in individual housing groups or in a small number of houses under scientific control, and very accurate condition, so called Pilot-projekt (Höglund et al, 1981).

So far however, nobody in Sweden has investigated the average true effects of different technical energy-saving measures on the basis of energy consumption, in a large number of houses selected at random, where different measures have been carried out. (Bostadsdepartementet 1981).

Both pilot projekts and statistical investigation are necessary for evaluation of the Energy Conservation Plan.

The main theme of this investigation has been to evaluate the true effects of energy-saving measures by selecting a large number of houses at random where such measures have been carried out. In total, 1144 buildings have been inspected comprising 944 single-family houses and 200 multi-family houses. The investigation was carried out in the following five counties: Norrbotten, Västerbotten, Stockholm, Göteborg-Bohus and Malmöhus. See fig. 1.

The measures/combination of measures studied in the investigation were selected becauce they had, to date, attracted most of the government support and/or were very common.