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EVALUATION OF THE EFFECTS OF ENERGY CONSERVATION MEASURES IN EXISTING BUILDINGS

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BACKGROUND AND GOALS

The energy situation in the world makes it a very urgent matter to reduce Sweden's dependence upon imported fuel - primarily oil. Energy conservation is an important and necessary means of achieving this goal. About 40% of the total energy consumption in Sweden is used for the heating and ventilation of homes and business premises. A reduction of such consumption by means of energy-saving measures is then an important part of energy conservation generally. As early as 1 July 1974 - a short time after the first oil crisis - the government took steps to stimulate energy saving in homes and business premises by granting loans and subsidies. At the same time a comprehensive investigation of the possibilities and conditions for taking comprehensive energy-saving measures in existing housing was begun. The investigation resulted in the Swedish Parliament adopting in the spring of 1978 an "Energy-saving plan for existing buildings". The energy-saving plan covers a ten-year period. The goal is to achieve by 1988 a gross energy saving of between 39 and 48 TWh per year, which corresponds to a reduction of the total energy consumption in today's buildings of 25-30%. The saving program involves considerable changes in the existing stock of buildings. Almost 80% of all homes will be affected by one or more saving measures. It is estimated that the energy-saving program itself will cost the community 21-33 milliard Swedish crowns during the ten-year period. The total investments are estimated at 31-48 milliard Swedish crowns in 1977 prices. The saving program will be built up by stages. The program is based on voluntary efforts with a minimum of adminstrative controls.

Special subsidies and favourable loans are intended to provide sufficient stimulus.

A careful followup is planned with regard to, among other things, the voluntary carrying out of the energy-saving plan. A review of the plan is scheduled in 1981. The main purpose of the present investigation is to survey the effects which are obtained in practice from energy-saving measures in existing buildings. It is intended to provide a basis for judging whether the theoretical calculations upon which the energy-saving plan is based, are acceptable. The investigation was begun in the spring of 1979, and it was intended that the results would become available in the spring of 1980. The studies must therefore be based upon data which can be obtained from already modified buildings.

MEASURES FOR SAVING ENERGY

A series of structural as well as installational measures are carried out in the existing stock of buildings. A list of the measures which have qualified for or which qualify for public support is given in Appendix 1. There are many different measures which can be carried out. The basic idea in the energy-saving plan is that measures which require little change in the building and which are relatively simply and cheap to do shall be carried out in a large number of houses. Major changes such as extra insulation of facades are usually done in connection with normal facade renovation. During fiscal year 1977/78 support for energy saving was granted for a total of about 54 000 buildings.

Among structural changes, extra attic insulation was often carried out due to easy accessibility. Extra insulation of outer walls in connection with facade renovation has also been common. Even relatively expensive measures such as changing to three-pane windows have been carried out to a certain extent, probably because moisture damage is common

in windows. Sealing of windows has probably also been carried out to a considerably extent. Among installational measures, the replacement of boilers and burners has been done in many houses. Furthermore, measures for controlling and regulating the heat supply predominate. The installation of thermostat valves has also been done to a considerable extent. Ventilation heat exchangers, however, have not been installed to any great extent in existing housing.

To achieve optimal energy saving it is most often advisable to combine structural with installational measures. The full effect of, for example, extra insulation is first obtained after manual setting or thermostatic regulation of the heat supply.

Various energy-saving measures have been combined in a large number of ways. Some impression of this is obtained by studying 100 randomly chosen buildings which received loans or subsidies. Thirteen different measures had been taken and they had been combined in 39 different ways.

ORGANISATION OF THE EVALUATION

The purpose of this study, as mentioned above, is to evaluate the effects of various energy-saving measures. The main principle in the organisation of the study has been to consider a large number of randomly chosen buildings in which energy-saving measures have been taken. The saving effects are obtained by comparing the energy consumption before and after the carrying out of the measures. It was considered necessary to determine, by means of a special method of calculation, the energy consumption for the entire heating season both before and after the measures were carried out. The evaluation was made in cooperation with a number of institutes of technology in Sweden. About 800-900 buildings were studied in the Stockholm region, and about 400 each in southern, western and northern Sweden. An estimated total of 2000-2500 buildings is included in the study.

The studies were defined in the following way.

- the measures must have been undertaken during the period 1 July 1975 - 30 June 1978
- the following measures and their combinations were studied in all regions

a)	extra attic insulation (sloping roof, tie-beam framework, braced wall)	in one-family houses
b)	extra wall insulation	
c)	measure a) combined with measure b)	
d)	thermostat valves combined with measure a)	
e)	extra wall insulation	in multi-family houses
f)	extra attic insulation combined with e)	
g)	thermostat valves	
h)	thermostat valves combined with variable controls	

In the Stockholm region an additional number of measure combinations were studied, of which the replacement of boiler and burner are especially interesting.

- the method of heating must be such that the energy consumption can be measured separately for the building
- rebuilding and extension must not have caused the heated volume to change
- residents' behaviour has such a great effect upon the energy consumption in one-family houses that such houses must not have changed families during the period of the study
- one family houses must be either separate or row houses with at most two flats
- multi-family houses must contain at least five flats and at least 75% of the area must be used for residential purposes

COLLECTION OF INFORMATION

Information on which measures were taken in different buildings is available in official agency documents. Pilot studies have shown, however, that very important deviations from this information occur in practice. It has been shown, among other things, that many more measures were taken than those for which loans and subsidies were sought, which is interpreted to mean that the interest in saving energy is great. Each building must therefore be examined carefully. For this reason a comprehensive inspection questionnaire was worked out.

The main purpose of the work with the questionnaire was to obtain information on completed energy-saving measures and energy consumption before and after carrying out the measures. The secondary purpose was to survey the buildings from both installational and structural viewpoints. The collected information is in fact regarded as also providing a basis for other research tasks and detailed analyses of the relations between energy consumption and the technical design, age, typ etc of the houses.

The file of completed questionnaires can function as a kind of data bank. Since the buildings were chosen at random, statistical data can be obtained from the material.

Information on energy consumption in the buildings was sought from July 1971 and afterwards. The information includes both housekeeping electricity and energy for heating. In those cases where information for this entire period was scarce, the aim has been to get information for at least one heating season before and after the time of the measure(s) studied. Information on energy consumption is normally obtained from the respective house owners or caretakers. However, it has proved to be possible to get information directly from oil companies or energy plants.

Questions which deal with energy-saving measures are listed under various headings such as extra insulation, heat production, heat regulation and heat distribution. The questions are mainly concerned with measures which qualify and have qualified for loans and subsidies. But other measures, for example, sealing of windows, have also been included. Also included is a series of questions on building construction, design and use, for example:

- survey of building construction with respect to form, type and material
- survey of the building's heat-production plant in which are also included questions on operation and maintenance
- survey of the building's heat-distribution installation
- survey of the building's ventilation system
- questions on tap hot water in the building
- survey of the building's central heat-regulation system
- survey of the measures which essentially changed the building's living area, such as extension, fitting of attic or cellar as well as change of owner

The questionnaire was designed for mechanical data processing.

METHOD OF CALCULATION

The method of calculation was worked out so as to be generally applicable to the project. The main purpose is to evaluate changes in the energy needed for heating. This has led to certain simplifications and the introduction of several standard values. Consequently the method of calculation is not intended to be used for calculating the actual energy requirements of the buildings. The main purpose, therefore, is to correct the energy consumption for heating alone to

the normal yearly values so that the energy-consumption information for different years can be mutually compared. The energy consumption for heating is thus assumed to depend only upon the indoor-outdoor temperature difference. The indoor temperature is assumed to be +21 °C. The average monthly values of the outdoor temperature comprise the input values. The need for heating energy is assumed to exist only between 15 September and 15 May for the Stockholm region. It is recommended that the other regions determine the length of the heating season in a similar way. Thus, the fact that the actual heating season may begin or end somewhat earlier or later in different years is ignored. Checking has shown that this assumption has a negligible effect on the final result.

The energy consumption for hot-water heating is calculated by means of standard values. Hot-water consumption is thus assumed to be equally large every day.

Housekeeping electricity consumption is treated in two different ways in order to avoid making concersions between different forms of energy in the calculations. In non-electrically heated houses the housekeeping electricity consumption is not included in the calculations. This implies an assumption that the housekeeping electricity consumption is not affected by energy-saving measures. In electrically-heated houses the housekeeping electricity consumption is calculated by means of standard values. The housekeeping electricity consumption is furthermore assumed to be equally large every day.

CALCULATION TO CORRECT ENERGY CONSUMPTION

Calculation of degree-hours

In the proposed method of calculation the indoor temperature is assumed to be +21 °C. This holds for both one-family and multi-family houses. The number of degree-hours which corresponds to each of the regions is calculated by means of the average monthly temperature which is obtained from the weather stations in the respective regions. This means that the outdoor temperature for calculating degree-hours is chosen from the most representative weather station for each building. The temperatures from the relevant weather station are obtained from the Swedish National Meteorological and Hydrological Institute.

$$Q = (\vartheta_i - \vartheta_o) \cdot T$$

where Q is the number of degree-hours per month

ϑ_i is the indoor temperature

ϑ_o is the average monthly temperature

T is the time in hours

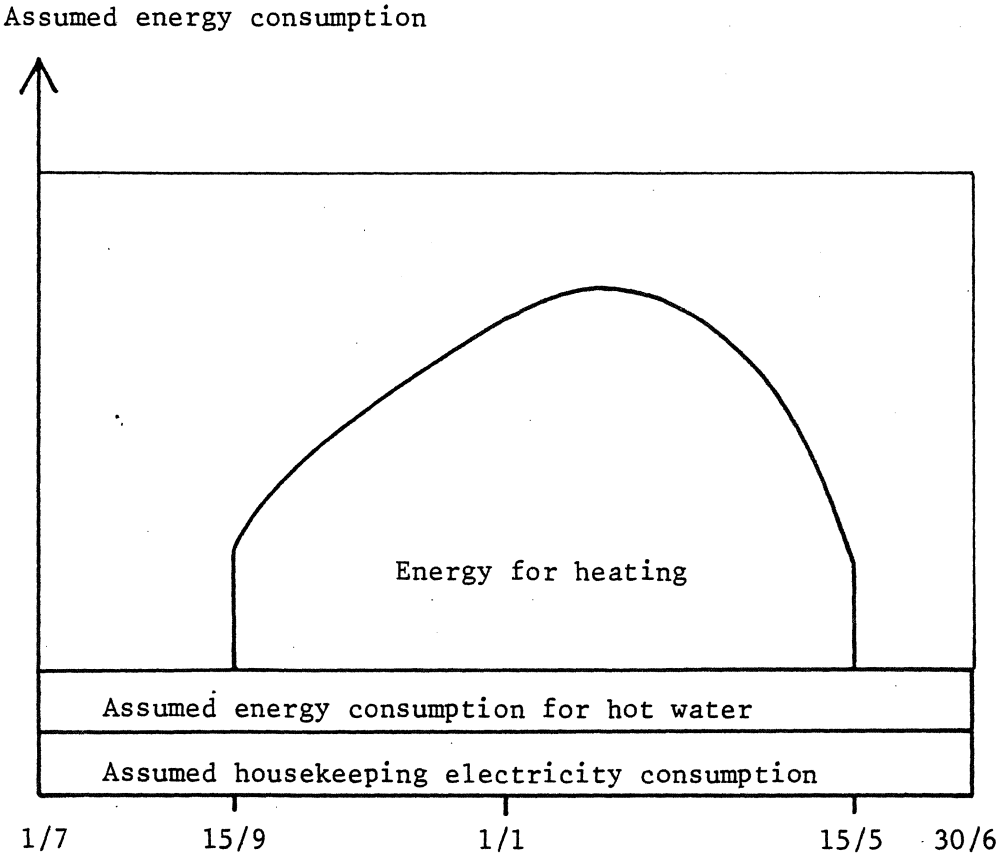
Determination of heating season

The heating season is assumed to extend from 15 September to 15 May. This heating season is the established practice for the Stockholm region. During the period 15 May to 15 September it is assumed that no intentional heating is needed, so-called free heat is assumed to cover completely the need for heating energy. In calculating the number of degree-hours for parts of months it is assumed for the sake of simplicity that all the days in a given month have the same temperature.

Energy for hot-water heating and housekeeping

In the calculations it is assumed that the energy consumption for hot-water heating and electricity for housekeeping are not affected by the climate.

For electrically heated houses, housekeeping electricity and energy consumed in hot-water heating are separated by means of standard values. This consumption is evenly distributed over the entire year regardless of outdoor climate factors. The temperature-dependent electricity consumption is then distributed over the heating season (15 September - 15 May) in proportion to the number of degree-hours for each month, see fig 1.

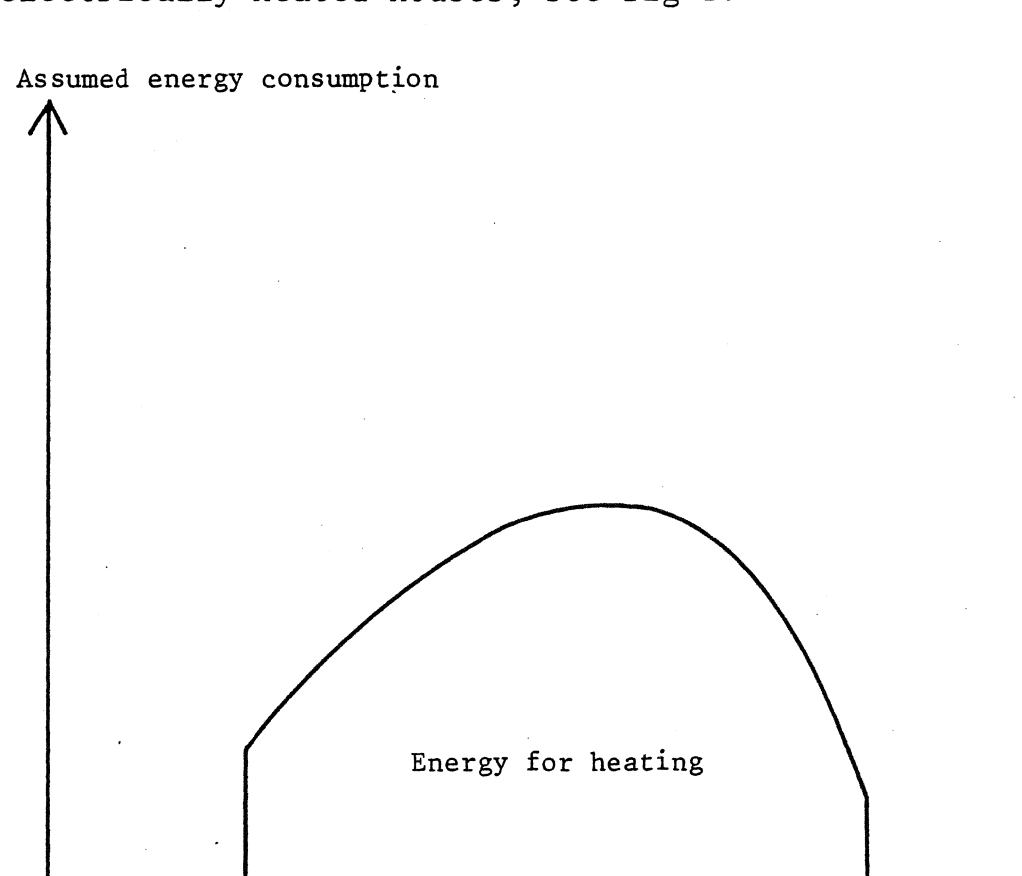


Figur 1

Basic method of calculation for electrically heated houses where the housekeeping electricity consumption is included in the total reading for energy consumption. In order to obtain a comparison with non-electrically heated houses a deduction is made for housekeeping electricity by means of a standard value.

For houses with other heating systems, standard values are used only for the energy for hot-water heating. The actual housekeeping electricity consumption is not considered in the saving calculation itself, since one would otherwise be obliged to compare different forms of energy.

The temperature-dependent and the temperature-independent energy consumptions are distributed in the same way as for electrically heated houses, see fig 2.



Figur 2

Assumed basic distribution for non-electrically heated houses. The method of calculation does not consider the actual housekeeping electricity consumption in this case.

ASSUMED STANDARD VALUES

Energy for hot-water consumption

One-family houses	4000 kWh/year or 500 liters of oil/year
Multi-family houses	3500 kWh/year and flat or 450 liters of oil/year and flat

Housekeeping electricity consumption in electrically-heated one-family houses 3200 kWh/year

SAVING OF ENERGY

In calculating the achieved energy savings, the climate-corrected energy consumptions are compared for entire heating seasons, that is, energy consumptions for the period 1 July - 30 June. If there are more than one heating season before or after the measure taken, the average of the consumption values for the respective seasons is used. It was considered quite justifiable to base the energy-saving calculations on whole-year consumptions, since in the method of calculation it is not possible properly to correct for, among other things, climate factors apart from the effect ot outdoor temperature, yearly variations in the efficiency of heating plants, seasonally dependent functioning of, for example, thermostats. Furthermore, although it was thought necessary to report the savings in similar ways, the energy savings are reported in different quantities. The reason for this is that different measures have different effects on the energy consumption. For example, burner and/or boiler replacement means an improvement in the efficiency of the heating system and therefore the saving should perhaps be reported as a percent. Extra insulation of an attic or of outer walls, on the other hand, reduces the heat transport through that part of the building and should therefore be reported as a saving per unit area or possibly per unit

volume (since these units are functions of the insulation area).

While waiting for closer studies of how the saving effects of the various measures and their combinations should be reported, the savings are determined in four different ways.

1 energy consumption/m^3 of heated volume

2 energy comsumption/m^2 of heated area

3 actual difference between the season before and after the measure was taken

4 $$\frac{W_{before}-W_{after}}{W_{before}} \cdot 100\%$$

where W is the energy consumption

The energy consumption may be given in liters of oil, kWh or m^3 of gas.

SOME OBSERVATIONS AND RESULTS

The investigation continues (October 1979) with data collection. Preliminary results are expected to be reported at the earliest in the beginning of 1980. One observation made so far, among others, is that the interest in saving energy in general proved to be great among the property owners who cooperated in the investigation. This is shown partly by the fact that they cooperated in the investigation in a positive way, and partly by the fact that in many cases entirely at their own expense they carried out measures for which public support could have been obtained.

Among the tendencies toward results which could be discerned are the following. The measure "extra attic insulation" leads to substantial energy saving. Somewhat greater and more stable saving effects seem to be achieved when this measure is combined with "radiator valves with thermostat". Replacement of boiler and burner in multi-family houses shows a tendency to give substantial savings.

LIST OF ENERGY-SAVING MEASURES FOR WHICH PUBLIC SUPPORT IN THE FORM AV LOANS AND SUBSIDIES IS GRANTED.

The extent of the support has varied somewhat from year to year.

Extra insulation

Attic
Ground flooring
Outer wall (also foam)
Three-pane window
Sealing with foam - floor-wall joint
Sealing with foam - crawl space

Heat production

Replacement of heating boiler
Replacement of oil unit
Equipment for heating with wood chips
Heat pump
Solar heating system
Automatic heating system (damper regulator)
Connection to district heating

Heat regulation

Variable control equipment (multi-family houses)
Motor shunt valve with thermostat with outdoor temperature indicator and time control (single family houses)
Radiator valve with thermostat
Circulation pump
Adjustment of heating system

Heat measurement

Distribution meter
Flow meter
Energy meter
Remote meter

Heat storage

Electrical installation for night storage of tap hot-water

Ventilation

Adjustable flow of exhaust air
Heat recovery from exhaust air
Adjustment of ventilation system

Other (measures which as a rule do not qualify for subsidy)

Sealing of all windows
Removal of inner reveal and sealing around window frames
Reduced room temperature