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Right combination of measures in the right building at the right time

Energy conservation in the form of combinations of measures

Swedish Council for Building Research

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0. THE PRINCIPAL CONTENTS OF THE INVESTIGATION

In the spring of 1978 the Swedish Riksdag passed a resoulution concerning an energy conservation plan for the existing building stock (Bill 77/78:76). The object is to reduce energy consumption in the existing building stock by about 25% over a ten-year period ending in 1988. The Riksdag also resolved that the conservation plan should be reviewed after three years. In conjunction with the current review, the Secretariat of the Energy Management Delegation has entrusted to the Swedish Council for Building Research BFR the task of investigating the matter of energy conservation in form of combinations of measures.

In the course of the investigation a new method, termed MINISYSTEM ANALYSIS, (MSA) was developed for the calculation of the energy conservation potential of an individual building in which a number of energy conservation measures interact. In this method account is taken of the fact that effects cannot at all times be added, and that certain measures must always be combined in order that the full effect may be obtained.

The investigation deals only with technical measures which require some kind of investment. The conservation potential of the measures is calculated on the basis of the assumption that the buildings meet certain minimum requirements regarding operation and maintenance.

In order that technically and economically optimal energy savings may be achieved, the different technical measures must be combined into correctly designed combinations of measures which are applied at the correct time. This correctly designed combination of measures for an individual building is put together on the basis of energy audit, calculation and analysis of the calculation results. From the point of view of energy, each building is an individual, and the composition of the combination will therefore vary from building to building, even though, to all appearances, the buildings are identical.

Applied examples of the calculation model for individual buildings show that the measures which require work on the facade are mainly profitable when they are carried out in conjunction with the repair of damage to the facade, maintenance or alteration. The MSA-method shows that building measures are chiefly profitable in single family houses, while installation engineering measures should mainly be carried out in blocks of flats and non-residential buildings.

Owing to the fact that minisystem analysis can be computerised, extensive calculations can be performed. The method can therefore also be applied for planning at municipal level, and for the calculation of the total energy conservation potential in the buildings of the country as a whole.

1. INTRODUCTION

1.1 The instructions from the Secretariat of the Energy Management Delegation

The Energy Management Delegation EHD has discussed with the Swedish Council for Building Research BFR concerning the feasibility, in conjunction with the overall reassessment of the energy conservation plan, of examining energy conservation in the form of combinations of measures, minisystem analysis.

The ideas concerning energy conservation in the form of a combination of measures have been developed over the past few years, among others in the programme groups set up to formulate the research programme of BFR in the energy sector, EFUD 81-84. In minisystem analysis a calculation is made of the conservation potential of different combinations of measures when these are applied to an individual building. In this process, acount is taken of the fact that certain measures must always be taken in conjunction in order that energy conservation may be secured, and also that the conservation effect of a combination may be less than the sum of the effects of the constituent measures. Minisystem analysis deals with the conservation achieved in an individual building. By aggregating the results from a number of buildings, it is possible to calculate the conservation potential for larger groups of buildings, for municipalities or even the whole of the country. It is essential however for such calculations that the energy properties of the buildings concerned should be reasonably well known.

1.2 The investigation

In order to associate existing knowledge in this subject area and to develop this calculation method, a special working group was formed by BFR. Members of this group were

Ingrid Munro Chairman	BFR
Dage Kåberger Vice-Chairman	member of BFR Board
Anders Eriksson	Bengt Dahlgren AB, Göteborg
Tore Hansson	Royal Institute of Technology, Stockholm
Anders Nilson	Bengt Dahlgren AB, Göteborg
Claes-Göran Stadler	Rockwool AB

In the course of its work, the group has been in contact with a number of people employed by authorities, institutions and firms. Among others, mention must be made of Bo Adamsson, Sven-Erik Bjerking, Gunnar Franzén and David Södergren. During its work, the group drew up a number of memoranda, and gave two presentations for the Energy Management Delegation.

1.3 Energy conservation in the form of a combination of measures

The basic premise of the method described in this report has been that energy conservation is most successful if it is carreid out in the form of correctly designed combinations of measures applied at the right time. This approach is new and differs in some respects from the method previously applied. By making savings in the form of a combination of measures it is possible to achieve technical, economic and administrative advantages. This report mainly deals with the way in which combinations of measures are made up from the technical point of view, and the way their scope is determined by economic criteria.

When potential energy savings are assessed, the traditional way is to divide the measures into

- building measures and
- installation measures.

Examples of building measures are

- additional insulation of
  - attic floors or roofs
  - external walls
  - windows and doors
  - ground floors
- increasing the airtightness of
  - windows and doors
  - floors
  - external walls.

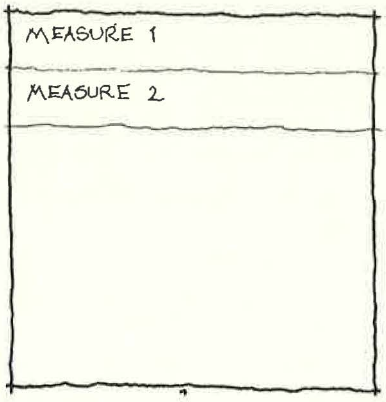
Examples of installation engineering measures are

- increasing the effectiveness of heat production
- increasing the effectiveness of heat distribution in the building
- adjustment of the heating system
  - automatic regulation of the mixer valve
  - use of thermostatic valves
  - time control
- adjustment of ventilation installation
  - adjustment of air flows
  - time control of air flows
  - recovery of heat from the exhaust air
- sealing of ventilation ducts.

In most of the previous investigations, for instance that forming the basis of the energy conservation plan, each measure is dealt with individually. When a number of measures are taken simultaneously, it is considered that the aggregate effect is 15% less than if the effects of these measures are added. This is the stereotyped method.

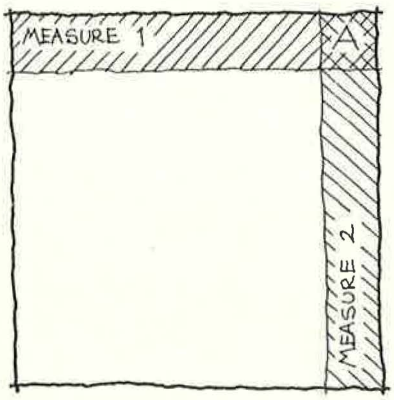
In the minisystem analysis several measures are applied simultaneously. Account is taken of the fact that the effect of certain measures cannot be added directly. This problem is illustrated by the following figures.

Two measures whose effects can be added without reduction.



An example of two such measures is additional insulation and the installation of a thermostatic mixer for hot water.

Two measures whose effects must be reduced on addition.



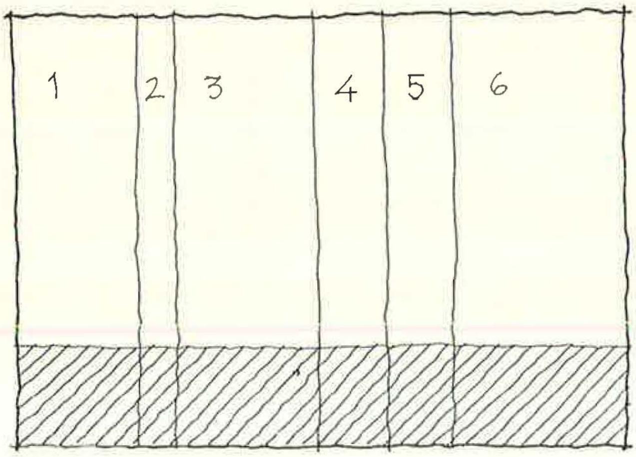
An example of two such measures is additional insulation and temperature regulation.

The outer frame represents the energy consumption of the building before the measures. If the effects of measures 1 and 2 are calculated independently, to give the <u>nominal saving</u>, the area A is counted twice.

If measures 1 and 2 form part of a combination of measures, the potential saving, the <u>possible saving</u>, is given by the applied calculation method as the whole of the shaded area, i.e. area A is counted only once.

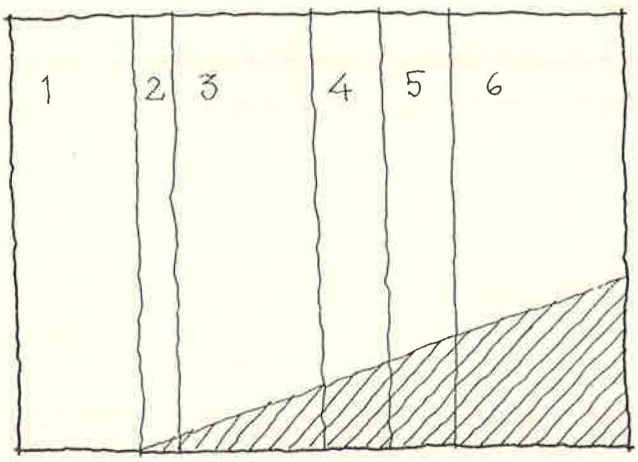
The minisystem analysis thus distinguishes between nominal and possible saving. This is essential in calculating the effect of energy conservation measures in the form of a combination, since a number of measures may be included in the combination. In the same way as the stereotyped method, the method of adding nominal savings can result in considerable errors.

The difference between actual and possible saving is greater, the higher the conservation cost of a measure in the combination, i.e. the higher its ordinal number in the combination structure. This phenomenon may be called the "triangle effect". This is best illustrated by the following figure.



Reduction according to the stereotyped method.

Measures for which the size of the area represents the size of the saving, and its ordinal number its ranking in the package from the point of view of profitability.



Reduction according to the "triangle effect"

Owing to the "triangle effect", the saving due to measures of a higher number is considerably reduced. The scope for energy conservation measures diminishes the greater the number of measures which are taken, i.e. the smaller the energy that the building requires. According to the previously used stereotyped method, this was not taken into consideration.

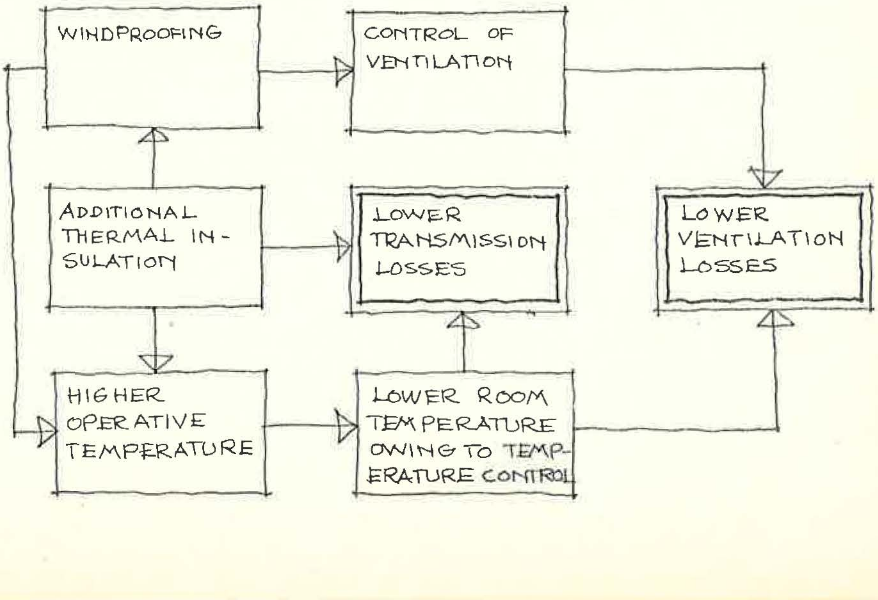
A combination of measures can include measures which are coupled. The term coupling implies that it is necessary for a certain measure to be carried out in order that the effect of another effect may be secured. Coupling is thus an essential requirement in order that the conservation potential may be accomplished to the full.
Examples of coupling are

additional thermal insulation and temperature control (Owing to addition thermal insulation the demand for input power diminishes, and for this reason a temperature control which reduces the supply or heat is required).

additional thermal insulation and airtightness (Generally speaking, when external walls are provided with additional thermal insulation, considerable work is done to the building facade. It is therefore an advantage that measures to increase the airtightness of the climatic envelope, which would otherwise be difficult to take, should be carried out at the same time).

increasing the airtightness and control of ventilation (When the climatic envelope is made more airtight, the number of air changes in the different rooms of the building can be changed. In order that the air change rate should be sufficient in all rooms, it is therefore necessary for windproofing measures to be followed by control of the ventilation).

The way that measures such as additional thermal insulation, windproofing, control of ventilation and temperature are coupled is schematically illustrated in the figure below.



The composition of a combination of measures depends on the technical construction, quality and standard of the building. Apart from the above energy advantages, other technical, economic and administrative advantages can be achieved.

Technical advantages:

The gains due to the energy conservation measures are secured:

> Additional thermal insulation as the only measure does not save energy. Although loss of heat has certainly diminished, the same heating effect is supplied by the radiators, and the indoor temperature therefore rises and there is no saving in energy. Additional thermal insulation as a measure must therefore be combined with measures which ensure that the temperature does not exceed the previous level. Due to additional insulation, it is often possible for temperature to be reduced while maintaining comfort levels. Additional thermal insulation must at all times be coupled with temperature control in order that the energy saving may be secured.

Energy saving accompanied by unchanged or improved comfort:

> Owing to temperature control, temperature will be reduced in most rooms. The inhabitants will then become aware of the climatic weaknesses of the room in the form of draughts and radiation. In order to ensure that there is no reduction in comfort, temperature regulation must be combined with additional insulation and windproofing as a combination. Temperature adjustments should be effected in the autumn to ensure that they are not regarded negatively.

Quality of workmanship:

> Energy conservation measures in the form of a combination demand simultaneous major work inputs, and for this reason work is likely to be carried out by larger established firms. This should result in better workmanship.

The energy conservation measures are done in the correct technical sequence:

> Major work with a view to saving energy should be carried out only once during the remaining life of the building. In conjunction with this work, it makes economic sense to inspect the building and to ensure that such inspection results in the measures having the proper scope. If the measures are taken one by one, it is possible for a previously carried out measure to be superfluous when the next one is taken.

Energy conservation measures are taken in properly selected buildings:

Owing to inspection and consultation, comprehensive energy conservation measures can be concentrated in buildings which are in need of maintenance, conversion or other action favourable to the energy conservation measures.

Economic advantages:

The costs of energy conservation and maintenance are combined:

From the economic point of view, it is profitable to carry out major energy conservation measures in conjunction with other work on the building, e.g. maintenance. This ensures that the energy conservation measures are marginal, since maintenance must in any case be carried out. Energy conservation measures need not bear the cost of e.g. scaffolding.

The costs of settling-in, supervision and scaffolding are combined:

Owing to the fact that a site is set up to carry out all the energy conservation measures in a building, the initial costs are spread over all the individual measures in the package. The package is therefore cheaper than if each measure were carreid out one by one.

More advantageous tenders:

Owing to the costs being combined as above, tenders should be more advantageous. In addition, it is to be expected that energy conservation measures will become such large contracts that large established firms will find the market of interest, and this should prevent the entry of firms of lesser standing.

Larger established firms:

See above. Energy conservation will demand broader competence than traditional construction. It may therefore be opportune for firms with special competence to be developed.

Rational utilization of resources: manpower and material:

At large workingsites and with larger established firms the manpower can be more evenly distributed and in the same way materials can be handled and stored in such a way that more rational production is achieved.

Administrative advantages:

Only one inspection of each building:

Energy conservation in the form of a combination requires only one inspection to decide the composition of the combination.

Fewer applications:

Owing to the fact that energy conservation measures are concentrated in a combination, there will be fewer applications for energy conservation grants.

Quicker processing by the authorities:

Owing to the fact that the authorities will receive fewer applications, and that these are based on inspections of a high standard, processing should be quicker and easier.

The inhabitants need be disturbed only once:

Owing to energy conservation measures in the form of a combination, work will be carried out only once during the remaining service life of the building. This should cause less disruption to the inhabitants than if they were bothered by builders on several occasions.

Only one final inspection:

Owing to the fact that there will be fewer sites, inspection by the authorities and property managers will be simpler. The cost of inspection will be lower, and the quality of inspection higher.

2. THE CONDITIONS FOR MINISYSTEM ANALYSIS

2.1 The energy balance for a building

Over a longer period, the energy losses and energy gains for a building are in balance.

The losses are

transmission losses
through floors, walls, doors, windows and the roof

ventilation losses
in the form of controlled ventilation, leakage of air and opening of windows

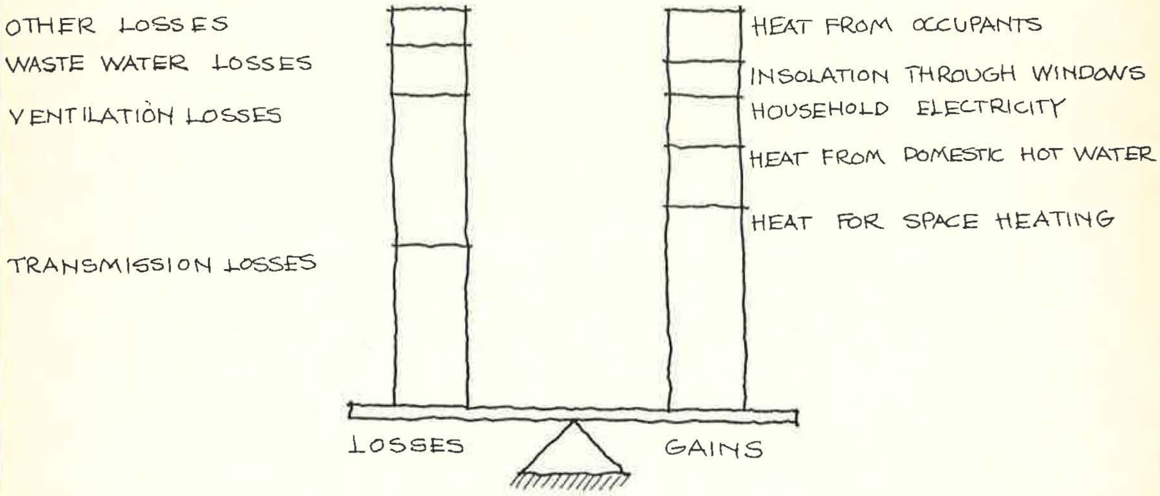
waste water losses
mainly in the form of heated waste water

other losses
that part of the energy supplied which is not utilised in the building
electric power for external lighting

The energy gains are due to

energy which is supplied to the building by the heating system
energy required for heating domestic hot water
energy dissipated by household electricity
energy from insolation through windows
energy from occupants in the building.

This balance can be illustrated as follows.



The gains in the figure are net gains, i.e. no account is taken of the losses in generation or transmission, for instance boiler losses in a domestic oil-fired boiler. Depending on the way the building and the hot water are heated, the net gains can be converted into gross gains or gross consumption. This conversion is different for different kinds of energy. In this investigation, the boundary for losses of efficiency in converting net to gross energy is taken to be the line of the facade, i.e. only those losses which occur in the building are taken into consideration. As far as electricity is concerned, all energy may be considered to be received by the building, while for an own boiler or the boiler house for a group of buildings the operational efficiency is taken into account. For district heating only the losses inside the building, i.e. in the heat exchanger, are taken into consideration.

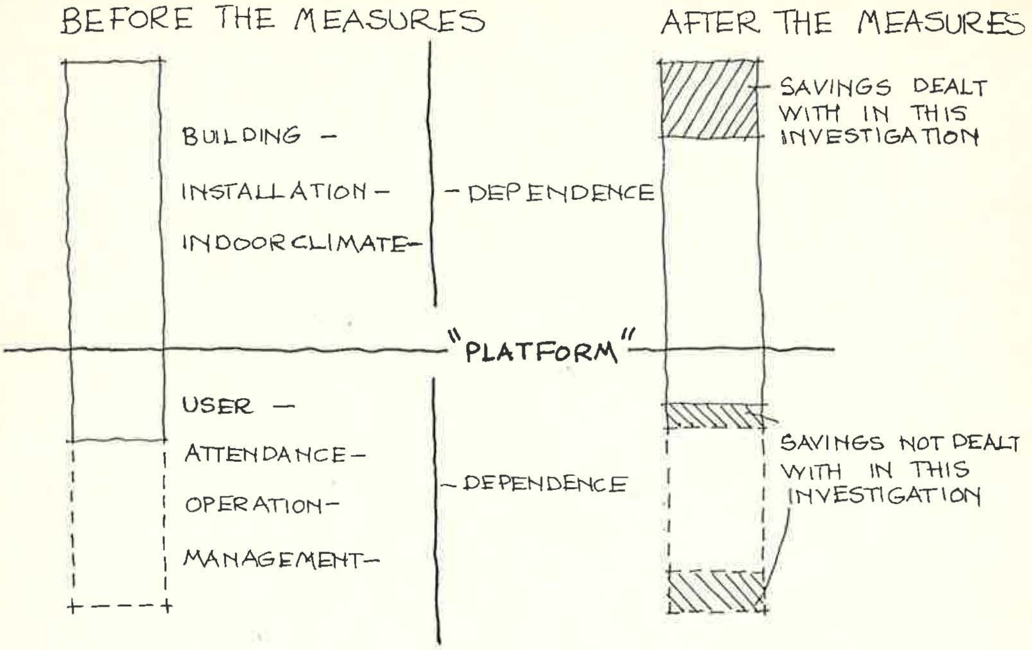
This balance is specific to each building. It depends on the size of the building, its shape, construction, installations and method of heating, and also on the geographical location of the building and its ambient microclimate. The consumption in two buildings which appear identical need not be the same. Varations may occur in the quality and airtightness of the construction. Consumption is in addition affected by the attendance, operation and management of the building, and by the people who use it.

The user influences energy consumption principally by his use of hot water, the opening of windows and the choice of room temperature level. In a single family house, energy requirement for hot water is normally 15-25% of the total energy consumption. Energy conservation measures reduce total energy consumption, which means that hot water acquires increased percentage significance in low energy houses. In these, consumption of hot water is of ever increasing importance.

In those cases where the user can choose the indoor temperature himself, the choice of a high indoor temperature results in increased energy consumption, 6-8% for each degree in excess of the normal.

The manager or the owner of a resident house can influence the energy consumption of the building in a number of ways: for instance by controling the level of indoor temperature and its distribution in non-residential premises and blocks of flats, and by maintenance of the building and its installations, i.e. tuning of the boiler, weatherproofing of doors and windows, and adjustment of the ventilation installation in buildings with mechanical exhaust or mechanical inlet and exhaust ventilation, etc.

The ease with which the factors which affect energy consumption in a building can be modified with a view to saving energy may vary, and the duration of this modifying effect may also differ from building to building. This investigation deals with technical measures in the building and its installations, and the changes in the indoor climate which these measures may result in. Measures require capital for their implementation, and are generally of long duration. The object of these measures is that the energy consumption of the building should be maintained at an optimal low level, provided that the building meets certain minimum requirements as regards maintenance, operation and attendance, which constitute a "platform" in this investigation. It is stipulated that there is regular replacement of nozzles, doors and windows are correctly weatherproofed, ventilation filters are replaced, etc. In order that operation, attendance and maintenance may be influenced, information to, and training of, both users and managers is necessary. However, issues like these are not dealt with in this investigation, nor changes to district heating, heat pumps or alternative sources of energy.

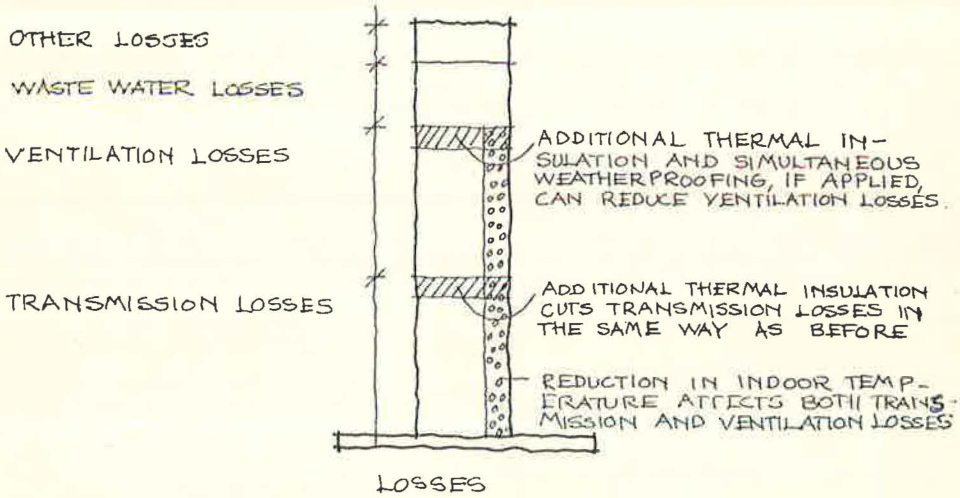


This investigation deals only with that part of energy consumption which is above the "platform", i.e. for which operation, attendance and maintenance meet certain minimum requirements. By means of information and training, energy savings can be made below the platform also. Optimum energy savings are achieved if gains are made both above and below the platform.

2.2 The effect of energy conservation measures on the energy balance

According to traditional models relating to energy conservation, a certain measure produces an effect on only one item in the loss column. Additional thermal insulation reduces transmission losses, weatherproofing reduces ventilation losses, and so on.

More recent findings have shown that certain measures may have an effect on several items in the loss column. As before, additional thermal insulation reduces transmission losses by reducing the U-value. In addition, insulation work can be done in such a way that airtightness increases, so that, where this is possible from the hygienic point of view, the ventilation losses can be reduced. In addition, owing to the fact that the surface temperature on the inside of the climatic envelope increases, it should be possible to reduce the indoor temperature slightly without this having a negative effect on comfort. Such a reduction cuts both transmission and ventilation losses.



The effects which can be ascribed to a certain measure must be determined in each individual case. The effect of the measures may however be limited by hygienic demands, for instance demands concerning minimum air change rate and acceptable room climate.

The calculation model for an energy conservation combination which is described in this investigation is designed in such a way that the effects of the measures can be modified to suit circumstances.

3. THE CALCULATION MODEL USED IN MINISYSTEM ANALYSIS

In order to calculate the effect of the energy conservation combinations and to assess the composition of the combination, a calculation model has been devised which consists of the following basic elements:

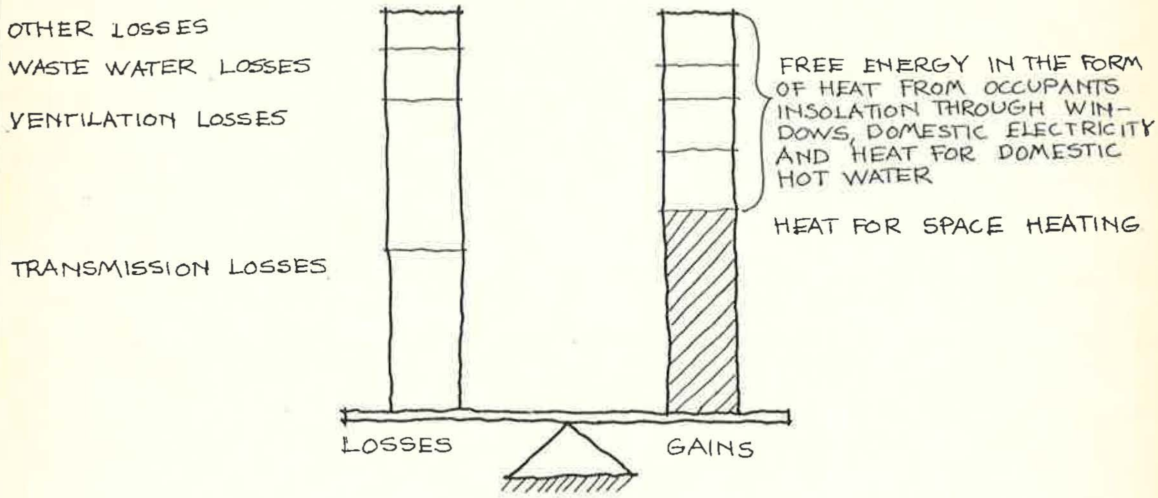
algorithm, see Section 3.1
(a formula which describes mathematically the relation between the measures and the savings)

analytical procedure, see Section 3.2
(a method of formalising the calculations)

measure of profitability, see Section 3.3
(a criterion which determines the size of the combination from the economic point of view).

3.1 Algorithm

The energy balance in a building forms the basis of the algorithm. This balance can be illustrated by the figure below.



Expressed in net terms, the balance can be written as
"Heat for space heating = all losses - free energy"

Expressed in gross terms, the same balance can be written as
"Heat for space heating$_{gr}$ = (all losses - free energy)$_{gr}$

The above relation can be expressed by the following formula:

$$W_{gross} = \frac{1}{\eta} \{ (K + V) \cdot Q + W \}$$

where

$K = \Sigma(k_i \cdot A_i)$ ($W/^{\circ}C$)   This term describes the transmission losses through the different surfaces i, where k_i is the thermal transmittance of building element i and A_i is its area.

$V = 0.33 \cdot n V_o$ $(W/^oC)$

This term describes the ventilation losses. n is the number of air changes per hour for the volume V_o. If the building comprises volumes with different air change rates, then this term will be the sum of all partial terms.

$W = W_{vv} - W_G$ $(W/^oC)$

This term is a "residual" term, where W_{vv} is the sum of "other" losses and waste water losses, and W_G is the free energy received in the form of insolation through windows, heat from occupants, domestic electricity and heat for the domestic hot water.

η = operational efficiency of the heat production plant, whether oil, electricity or district heating heat exchanger, over one year.

Q = annual degree hour factor (^oCH), see Section 3.13, which depends on t_R, t_u and L, where

t_R = mean indoor temperature

t_u = outdoor temperature

L = length of heating season

3.11 The effect of different measures

In order that it may be possible to calculate the effect of the measures and combinations of measures which have been taken, the effects must be converted into changes, both positive and negative ones, in the parameters in the algorithm. Changes in a parameter are indicated by putting the letter Δ in front of the appropriate symbol.

Certain measures are only capable of affecting one parameter, while others can affect several. Some likely measures and the parameters affected by these are set out below. The magnitude of this effect must be determined by inspection and assessment of the special circumstances applicable to the building in question. In Section 4 some examples are given of buildings and the assumed magnitudes of the effects.

Measure: Change of burner $\Delta\eta$ = .. % points

By changing the burner to a more modern type, efficiency can be increased, even in cases where the old one is optimally tuned for its design.
If a comprehensive conservation measure combination is carried out, replacement of the burner is essential in order that the boiler may continue to work with at least the same efficiency.

Measure: Control of hot water temperature. ΔW_{VV}=..%	By reducing the temperature of the hot water, heat losses can be cut.
Measure: Central temperature control. Δt_R = ... ^oC	By installing a central controlling device for the flow temperature of the heating medium, the mean temperature can be reduced.
Measure: Adjustment of the heating system. Δt_R = .. ^oC	By adjusting the heating system, it is possible to reduce the differences in temperature between different rooms. In this way the mean temperature can be reduced.
Measure: Thermostatic valves. Δt_R = ... ^oC	By controlling emission of heat by the radiators, the room temperature can be reduced.
Measure: Time control of ventilation. Δn = .. ach	By timing control of ventilation, it is possible to reduce this during certain parts of the day. This measure applies only in buildings with mechanical extract or mechanical inlet-extract ventilation.
Measure: Adjustment of the ventilation system. Δn = ... ach	By adjusting the ventilation system, it is possible to reduce the differences in air change rate. The mean air change rate can be reduced in this way.

Measure: Heat recovery, ventilation. $\Delta\eta_{vx}$ = ... %

By installing a heat exchanger in buildings with mechanical inlet and extract ventilation, some of the heat in the extract air can be returned to the building.

Measures with SEVERAL effects:

Measure: Additional thermal insulation of external wall.

Δm_t = ... $^oCm^2/W$

Δn = ... ac/h

Δt_R = ... ^oC

Additional thermal insulation results in an increment m_t to thermal resistance. This reduces the thermal transmittance of the construction. Weatherproofing of such extent may be considered that a reduction in the air change rate is possible. The room temperature can often be reduced without an adverse effect on comfort.

Measure: Additional thermal insulation of attic floor.

Δm_t = ... $^oCm^2/W$

Δn = ... ac/h

Additional thermal insulation results in an increment m_t to thermal resistance. This reduces the original thermal transmittance of the construction. In special cases, in single family houses with attic rooms, improvements in airtightness can be achieved.

Measure: Replacement of windows and weatherproofing

Δm_t = ... $^oCm^2/W$

Δn = ... ac/h

Δt_R = ... ^oC

Additional thermal insulation is provided, for instance, by replacing the old double glazed window by a triple glazed one wich has higher thermal resistance. By better weatherproofing of the gap between frame and wall than before, the air change rate may also be reduced. It may be possible to reduce the room temperature without an adverse effect on comfort.

Measure: Conversion of window

Δm_t = ... $^oCm^2/W$

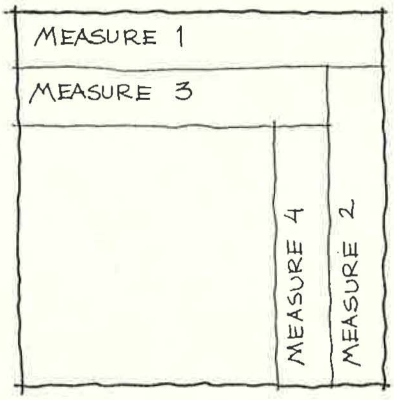
Δt_R = ... ^oC

Additional thermal insulation may be carried out by provision of an extra pane on the inside. This raises thermal resistance. It is often possible to reduce the room temperature without an adverse effect on comfort.

In addition to these measures which are primarily applicable to dwellings, other measures can also be tried in office buildings, schools, hospitals or industrial buildings. Such measures can also be catered for in the calculation model by describing their effects on the energy balance in terms similar to the above.

3.12 Interaction between measures

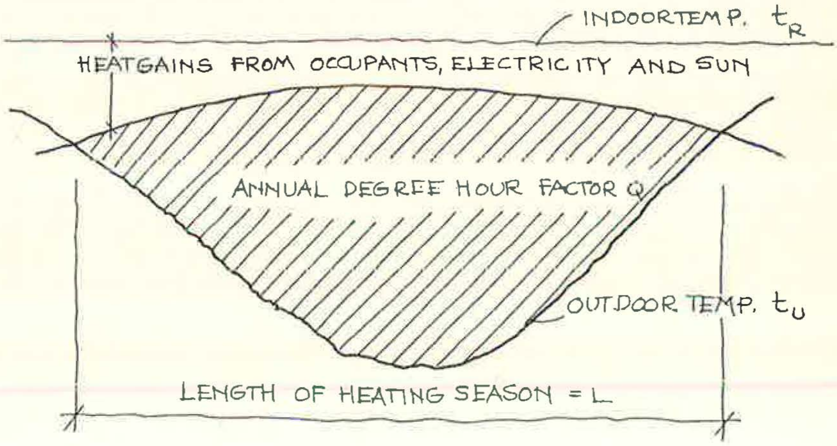
In order that the calculation should represent possible savings and not nominal ones, the fact that the building has attained a new energy balance after the first measure must be taken into consideration. When measure No 2 is taken, its effect is not counted from the original energy balance but from the one attained after measure No 1. In order therefore that the interaction between the measures in a combination comprising a number of measures should be taken into consideration, a new energy balance must be calculated after each and every one of the measures, i.e. the balance must be drawn up several times. This procedure is best illustrated by the figure below, in which the outer frame represents the original consumption. Owing to the first measure, consumption is reduced, and the actual conservation effect of the next measure cannot therefore be as large as its nominal effect, i.e. the one that would have been calculated if the measure had been taken on the original consumption.



Measures whose effects can be added, see Section 1.3, are exceptions to this procedure.

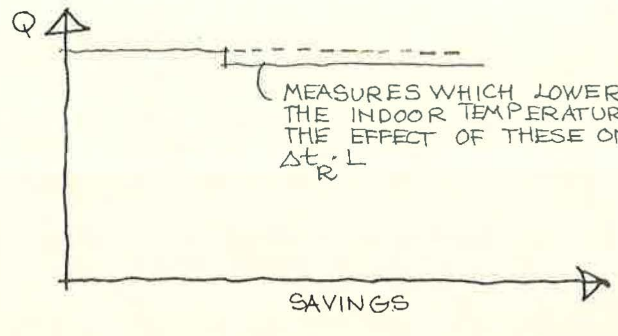
3.13 The annual degree hour factor Q

The annual degree hour factor Q is a measure of the heating requirement. Its magnitude, which varies from place to place in the country and from year to year, depends on the difference in indoor and outdoor temperature and on the length of time during the year when energy needs to be supplied. This magnitude is reduced by free energy in the form of solar gains, heat from occupants, heat from lighting, etc. The annual degree hour factor can be illustrated by the figure below.



Depending on the type of calculation to be carried out, the annual degree hour factor Q can be determined in a number of ways.

Method A: The indoor temperature is assumed to be +20°C. Energy gains are assumed to amount to about 3°C, and the building therefore needs to be heated to only +17°C by means of external energy. The annual degree hour factor can in this case be calculated as the difference between the outdoor temperature according to the Swedish Meteorological and Hydrological Institute SMHI and +17°C. There are certain rules for determination of the length of the heating season. According to this method the value of Q is not altered by energy conservation measures, with the exception of those which lower the indoor temperature. The variation in the value of Q as a function of the extent of savings is shown in the figure below.



Method B: In principle the same as Method A, but the indoor temperature is assumed to have a value more in keeping with actual conditions, e.g. +21^{o}C in single family houses and +22^{o}C in blocks of flats. The value of Q is assumed not to be altered by energy conservation measures, with the exception of those which lower the indoor temperature.

Method C: According to this method, account is taken of the fact that in buildings which consume less energy as a consequence of conservation measures the energy gains assume greater significance. This means that the need for external heating energy is less, Q is smaller, and the heating season is shorter. This state of affairs can be described by the formula

$$W = (K + V)Q_{before} - W_G = (K + V)Q', \text{ which can be}$$

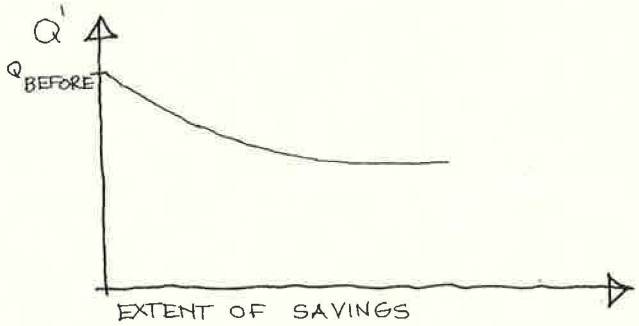
changed to

$$Q' = Q - \frac{W}{K+V}, \text{ where the denominator } (K + V) \text{ represents}$$

the energy requirement of the building.

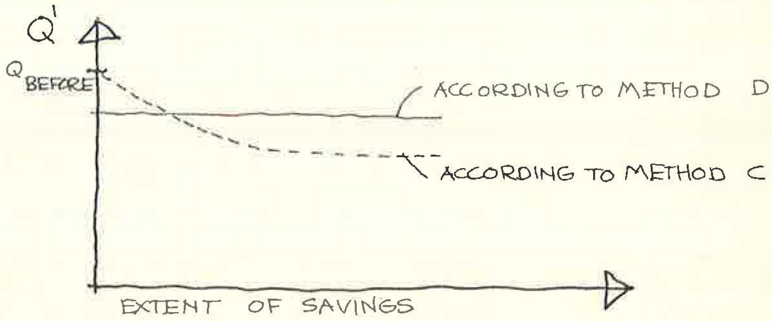
Owing to energy conservation measures the energy requirement of the building diminishes, which means that the last term increases.

The more energy conservation measures there are taken, the more the value of Q' diminishes. Its value can be illustrated by the figure below.



For a building, the value of Q' can be calculated after each measure. The above curve then becomes a stepped curve.

Method D: Method C can be simplified by assuming the value of Q' to remain constant regardless of the extent of savings.



When the extent of savings is calculated directly, without drawing up an energy balance, another Q-value can be used.

Bo Adamson at the Lund Institute of Technology has developed a method, which is an extension of Method C, by means of a marginal effect approach. This results in a definition of a fictitious Q-value, Q_{save}, using which the extent of the savings can be calculated more easily. Q_{save}, which increases with the increase in the extent of savings, can be treated as a constant or it may vary.

In the minisystem analysis, depending on the degree of refinement to be used, any of the methods A-D can be applied. Manuals usually quote a Q-value for different localities which corresponds to Method A. A change to other methods can be made on the basis of these data.

3.2 Analytical procedure

The object of the minisystem analysis is that it should be possible to describe the energy conservation potential of a combination of measures of variable scope as a function of a measure of profitability, e.g. the conservation cost. See Section 3.3.

Calculation of the energy conservation potential is done by drawing up the energy balance a number of times. The conservation potential of a certain measure is the difference between two energy balances. These repeated energy balance calculations and their results are described by the following schematic arrangement.

FIRST energy balance calculation:

Measure a)	Calculation of the nominal conservation potential as if measure a) were being taken on its own	Nominal conservation cost of measure a) in Skr/kWh
Measure b)	Calculation of the nominal conservation potential as if measure b) were being taken on its own	Nominal conservation cost of measure b) in Skr/kWh
Measure n)	Calculation of ...	Nominal ...

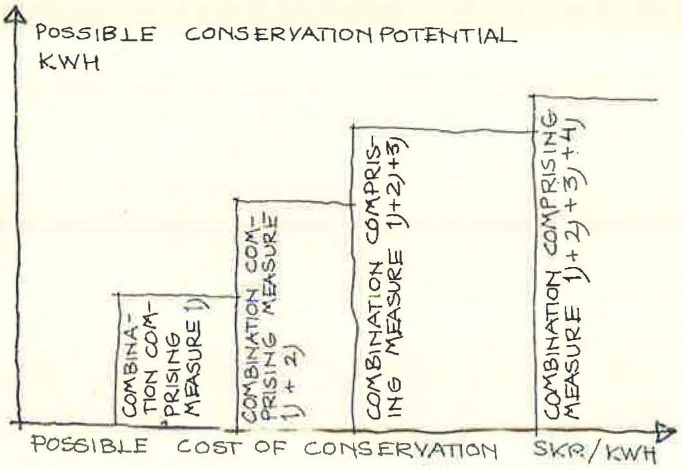
The measures are ranked in the order 1 - n on the basis of the nominal conservation cost of the measure, the lowest cost being given No 1. If the final result gives a ranking for the possible conservation cost of measures which is different from the nominal one, the ranking is adjusted and a second lot of calculations is carried out.

SECOND energy balance calculation:

Measure 1)	Calculation of the possible conservation potential of measure 1) when it is the first measure in a combination	Possible conservation cost of measure 1) in Skr/kWh when it is the first measure in a combination
Measure 2)	Calculation of the possible conservation potential of measure 2) when it forms part of a combination comprising measures 1) and 2)	Possible conservation cost of measure 2) in Skr/kWh when it forms part of a combination comprising measures 1) and 2)
Measure n)	....	....

The possible conservation potentials are aggregated, and indicate the actual conservation potential of a combination of measures of increasing scope.

Associated values of the aggregated conservation potential and the conservation cost can be set out in a diagram. This shows the economy of a combination of measures of variable scope



The above diagram shows the relationship between the possible conservation potential and the possible conservation cost for a given building of given properties which has been assigned a conservation measure combination comprising given measures whose effects can be achieved. If a certain measure is omitted from the combination, the curve relating to the measures with a higher cost than that omitted is changed. After a measure has been omitted, the entire calculation must be repeated.

The above curve has been obtained by calculating the energy balance for the building a large number of times. Owing to the large number of calculations, it is advantageous to use a computer.

THIRD energy balance calculation.

The measures are made up into a combination of measures. The possible conservation potential and the associated possible conservation cost are calculated in the same way as above by drawing up the energy balance. The calculation is based on the total change in the parameters brought about by the measures in the combination. The conservation cost calculated in this way will thus represent a kind of mean of the conservation costs of the constituent measures comprised in the combination.

3.3 Measure of profitability

The calculation model contains a profitability criterion which makes possible an economic assessment of the individual measures or combination of measures. There are a number of methods which are applied today for the calculation of profitability. Any of these can be used. By request of the Energy Management Delegation, it is the conservation cost (BK) which is used in this investigation, as in Bill 77/78:76.

The conservation cost is defined as

$$BK = \frac{\text{investment} + P_1 \cdot \text{annual maintenance cost}}{P_2 \cdot \text{annual saving in energy}} \quad \text{Skr/kWh}$$

where

$$P_1 = \frac{1-\left(\frac{1}{1+r}\right)^T}{\frac{r}{1+r}} \quad \text{and} \quad P_2 = \frac{1-\left(\frac{1+q}{1+r}\right)^T}{\frac{r-q}{1+r}}$$

The symbol r denotes the real discount rate and q the annual rise in the price of energy, expressed in real terms (or - to put it another way - the annual rise over and above inflation). T denotes the service life of the measure.

The conservation cost can also be expressed in words as

"The conservation cost is that price of energy which would make the present value of the savings equal to the sum of the investments and the present value of the maintenance costs." (Bill 77/78:76).

A combination of measures may comprise measures of different service lives T. Measures of shorter service lives require re-investments during the service life of the combination. This is taken into consideration by introducing in the above definition, for these measures, the words "the sum of the present values of the investments and...".

In the following, the concept used is the gross conservation cost which is obtained if the gross energy conservation is used in the above relation. Direct comparisons can then be made with the current price of energy, expressed in gross energy units (Skr/kWh).

3.31 Costs

For calculation of the conservation cost, the costs of carrying out the various measures must be reasonably well known. It must be possible to relate the costs to the appropriate measures. In this connection it must be noted that there is a risk that the same cost will be a charge on a number of measures. Scaffolding is required for additional thermal insulation of a facade, but also for replacement of windows. In the first calculation the cost of scaffolding must be equally apportioned to both the facade and the windows. If, in the final combinations, the windows are included but not the facade, the costs relating to the windows must be adjusted.

There are three fundamentally different ways of treating costs.

A) All the measures bear the full costs.

This means that the profitability of the measures is calculated on the supposition that the measures are carried out only with the aim of saving energy.

B) Certain measures bear only the marginal costs.

This means that the energy conservation measures are carried out in conjunction with other measures, so that the costs can be allocated to a number of jobs. Examples of other work which may become necessary in a building are

conversion
renovation
maintenance
repair of damage
modernisation.

C) Certain measures bear costs which are intermediate between full and marginal costs.

This means that conservation measures are carried out in conjunction with other measures which are however not immediately necessary but have been brought forward in order that the conservation measure may be carried out earlier. Examples of such measures are

bringing forward of renovation
bringing forward of maintenance
bringing forward of modernisation.

The effect of these different methods on the costs is illustrated by the following example.

A double-glazed window is to be replaced by a triple-glazed one. Both the frame and casement are to be replaced.

Method A).

The window is in perfect condition and well maintained. Cost = Skr. 2000 each, full cost. (If replacement of only the casements is necessary, there are other cheaper techniques).

Method B).

There is decay of such extent in both the frame and casement of the window that immediate replacement is essential. The full cost of Skr. 2000 as above will be apportioned between the energy estimate and the maintenance estimate.

Replacement of a damaged double-glazed window by a new double-glazed window costs Skr. 1800 each, and replacement by a new triple-glazed window Skr. 2000 each. If triple-glazed windows are installed, then

the energy account bears	Skr. 200 each, and
the maintenance account	Skr. 1800 each.

It is thus of considerable advantage to carry out conservation measures in buildings in which the costs can be charged to other necessary work.

Method C).

The window exhibits incipient damage. It is judged to have a remaining life of about 5 years. A new window is judged to have a life of 30 years. If a new triple-glazed window is installed 5 years earlier than necessary, then

the energy account bears

$$\text{Skr. } 200 + \frac{5}{30}\,1800 = 200 + 300 = \text{Skr. } 500 \text{ each}$$

the maintenance account bears

$$\text{Skr. } 1800 - 300 \qquad = \text{Skr. } 1500 \text{ each}$$

It may be of economic advantage to carry out energy conservation measures by bringing forward other work rather than to be forced to pay the full cost.

In the calculations for a combination of measures applied to a building, all three methods will be examined.

According to Method A), new investments made only with a view to energy conservation

According to Method B), marginal investments with a view to energy conservation carried out in conjunction with replacements necessitated by other considerations

According to Method C), partial investment with a view to energy conservation where new investment would later on have become necessary.

The calculations must therefore be based on sound assessments of the quality of the building and its installations and technical equipment, and also on assessments of the remaining useful life. The costs and properties of the energy conservation measures must be elucidated. If this is done, considerable gains can be made by

carrying out the right measures in
the right buildings at
the right time

3.32 The scope of the combination of measures

The possibilities of saving energy and the costs of this depend on a large number of factors. From the energy conservation point of view, every building is an individual. The potential savings cannot be assessed until an expert inspection has been made of the essential energy properties. It is essential that the correct costs of the measures which will be carried out are known.

The scope of a combination of measures is primarily determined by the attainable profitability. Normally, a combination should not include measures whose conservation cost is higher than the current price of energy for the method of heating used. It may however be necessary to include measures whose conservation cost is higher than the current price of energy, if such measures are essential for the function of the combination. It is however stipulated in such a case that the conservation cost of the combination as a whole should be lower than the current price of energy. This approach supposes that there is access to sufficient capital to finance the entire combination of measures.

If access to capital is limited, then consideration may be given to a combination of lesser scope. Such a reduced combination, includes only the most profitable measures. Often, when a combination of measures of reduced scope is carried out, the conditions relating to implementation of the remainder of the combination at a later date are changed. The reason for this is that, at this later date, certain measures must be repeated in order to secure the effect of the combination of measures as a whole, and also that the costs of e.g. inspection, consultation, settling-in and so on occur on both occasions. It may even happen that the conservation cost of the remaining part of the combination is so high that is is not possible to carry out a second round of measures. Issues of this nature must be gone into thoroughly before a decision is made to carry out parts of the combination. In the normal case, from the point of view of national economy it is right to carry out the whole combination of measures at one and the same time.

4. APPLICATION OF MINISYSTEM ANALYSIS AT BUILDING LEVEL

In order to illustrate how the calculation model works, it is applied to some building types,

a single family house, see Section 4.1
a block of flats, see Section 4.2
an office building, see Section 4.3.

Each example has been selected in such a way that the conditions differ to the greatest possible extent. In this way it will be possible to obtain indications concerning the potential and limitations of energy conservation.

4.1 Application of minisystem analysis to a single family house

A type of house which may be considered for energy conservation is the frame house built over the period 1930-1950. These were a further development of the timber boarded house. The walls were given better thermal insulation by filling the spaces between the uprights with sawdust. Windproofing consisted of building felt.

The assumptions underlying the calculation are set out below. In an actual case these assumptions should be based on an inspection of the house and an assessment of the effects and costs of the measures. It is assumed that the house is in need of facade renovation.

Input data for calculation of the energy balance before the measures:

Transmission losses: $\Sigma(k_i A_i)$

External walls	$U = 0.7\ W/m^{2\circ}C$
	$A = 125\ m^2$
Attic floor	$U = 0.6\ W/m^{2\circ}C$
	$A = 120\ m^2$
Ground floor	$U = 0.35\ W/m^{2\circ}C$
	$A = 120\ m^2$
Windows and doors	$U = 3.0\ W/m^{2\circ}C$
	$A = 25\ m^2$

Ventilation losses: $0.33\ n\ V_o$

$n = 0.8$ ach

$V_o = 297\ m^3$

Annual degree hour factor $Q = 97\ 000\ ^{o}Ch$. (Central Sweden) climate, indoor temperature = $+21^{o}C$. Domestic hot water = = 4500 kWh.

Operational efficiency of own boiler $\eta = 70\%$.

Proposed measures, their effects and costs:

Replacement of burner: $\Delta\eta = 5\%$ points
Cost = Skr. 3000

Intermittent heating: $\Delta t_R = 0.5^{o}C$
Cost = Skr. 3500

Additional thermal insulation and windproofing of roof:

$\Delta U = 0.39\ W/m^{2\,o}C$ 150 mm mineral wool, $m = 3.0\ m^{2\,o}C/W$
$\Delta n = 0.05$ ach

Cost = Skr. 80/m^2

Additional thermal insulation and windproofing of external wall:

$\Delta U = 0.41\ W/m^{2\,o}C$ 100 mm mineral wool, $m = 2.0\ m^{2\,o}C/W$
$\Delta n = 0.10$ ach

$\Delta t_R = 0.5^{o}C$

Cost = Skr.140/m^2. Marginal cost for the insulation since the work is carried out in conjunction with facade renovation.

Total cost is Skr. 300/m^2.

Conversion of windows:

$\Delta U = 1.0\ W/m^{2\,o}C$, a third pane is installed on the inside

$\Delta n = 0$ ach

$\Delta t_R = 0.5^{o}C$

Cost = Skr.300/m^2. The window is in perfect condition, and for this reason the whole cost is borne by energy conservation.

When the energy balance after the measures is calculated, Method B in Section 3.13 is used for calculation of the annual degree hour factor Q. According to this, $Q' = 120\ 000\ ^{o}Ch$ for Örebro.

Assumptions for the economic calculations:

Discount rate $r = 6\%$
Rise in price of energy: $q = 6\%$ over the first five years, after that $q = 2\%$.

Service life T:

Building measures	T = 30 years
Installation engineering measures	T = 15 years
but replacement of burner	T = 10 years

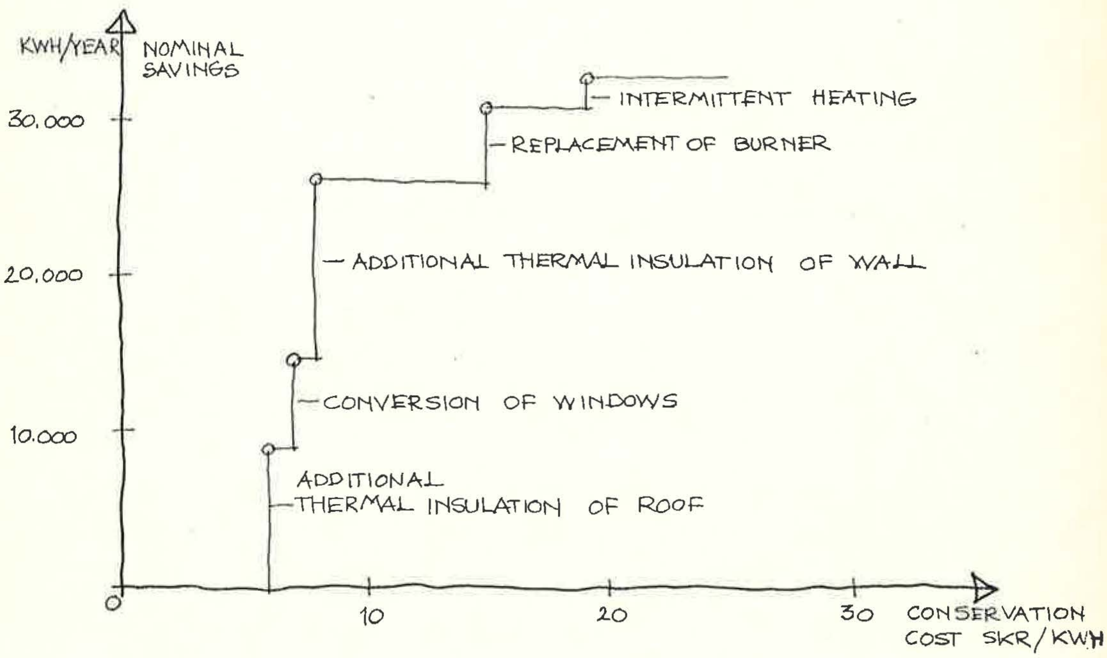
Results:

A) Energy consumption before the measures:

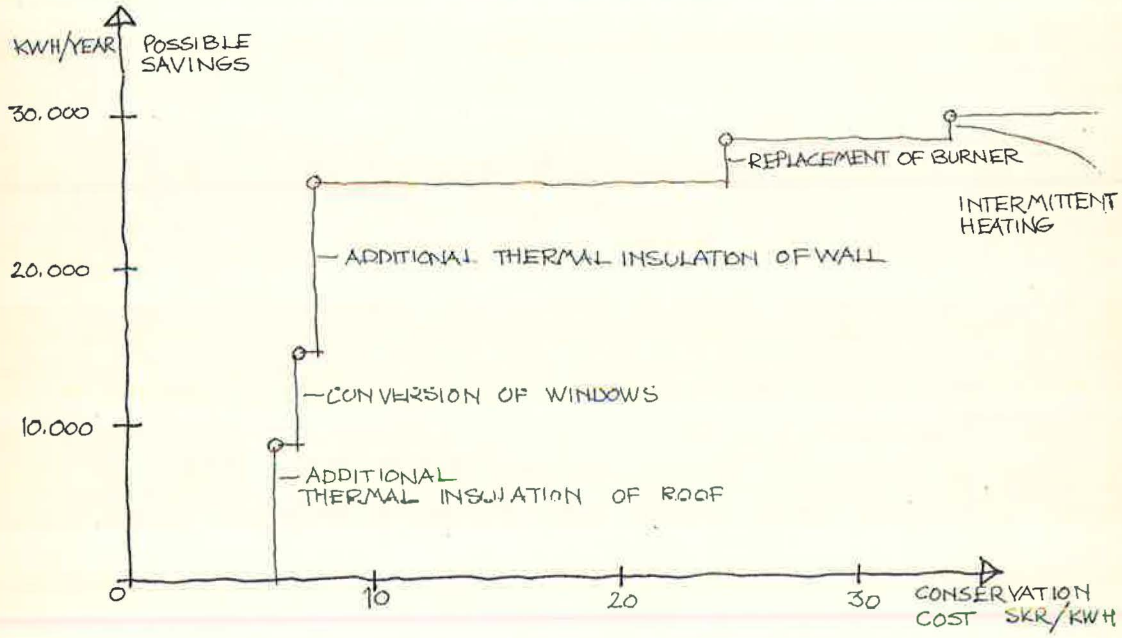
56 000 kWh annually

51 litres oil/m^2 annually

B) Nominal savings



C) Possible savings.



Measure	possible saving gross kWh	conservation cost Skr/kWh	initial investment Skr
Additional thermal insulation of roof	ca 9 000	0.06	9 600
Conversion of windows	5 000	0.07	7 500
Additional thermal insulation of wall	11 000	0.08	17 500
Replacement of burner	3 000	0.25	3 000
Intermittent heating	1 000	0.34	3 500

Comments:

At the current energy price level for fuel oil 1(Eo 1), about Skr. 1 500/m^3, with corresponds to about Skr. 0.15/kWh, in this case it is profitable to

convert the windows
additionally insulate and windproof the roof
additionally insulate and windproof the wall

The conservation potential is 28 000 kWh or about 25 litres oil/m^2 annually. On the other hand it is not profitable to carry out the proposed installations measures in view of the conservation costs of these being so high. None of these measures is such that they must, in view of their function, be associated, coupled with the others.

If the facade of the house had been in good condition, the cost of providing additional thermal insulation for the wall would have been higher, about double, which would have meant that the conservation cost of the measure had been increased from Skr. 0.09/kWh to about Skr. 0.18/kWh. The measure would then have been unprofitable. The combination would then have been restricted to

conversion of windows
additional thermal insulation and windproofing of the roof

for a house with the facade and windows in perfect condition.

4.2 Application of minisystem analysis to a block of flats

A building type which may come into consideration is the aerated concrete buildings constructed mainly in the 50s. The external walls of these buildings consist of aerated concrete blocks rendered on the outside. The floor slabs are of reinforced concrete. The assumptions underlying the calculations are set out below.

4.21 Building with a facade in need of renovation

Input data for calculation of the energy balance before the measures:

Transmission losses: $\Sigma(k_i A_i)$

External walls	$U = 0.7\ W/m^{2\circ}C$
	$A = 560\ m^2$
Basement wall	$U = 1.40\ W/m^{2\circ}C$
	$A = 172\ m^2$
Attic floor	$U = 0.7\ W/m^{2\circ}C$
	$A = 270\ m^2$
Ground floor	$U = 0.25\ W/m^{2\circ}C$
	$A = 247\ m^2$
Windows and doors	$U = 3.0\ W/m^{2\circ}C$
	$A = 142\ m^2$

Ventilation losses: $0.33\ n\ V_o$

Flats	$n = 0.6$ ach
	$V_o = 2025\ m^3$
Basement	$n = 0.3$ ach
	$V_o = 543\ m^3$

Annual degree hour factor $Q = 103\ 000\ ^oCh$, indoor temperature $+22^oC$. Hot water consumption: 42 000 kWh/year corresponding to 3 500 kWh/flat and year. Operational efficiency of own boiler: $\eta = 75\%$.

Proposed measures, their effects and costs:

Replacement of burner:	$\Delta\eta = 5\%$ points Cost = Skr. 5 000
Intermittent heating:	$\Delta t_R = 0.5^oC$ Cost = Skr. 7 000
Adjustment of heating system:	$\Delta t_R = 0.5^oC$ Cost = Skr. 3 000
Additional thermal insulation of roof:	$\Delta U = 0.47\ W/m^{2o}C$ Cost = Skr. $80/m^2$
Additional thermal insulation of wall:	$\Delta U = 0.41\ W/m^{2o}C$ $\Delta n = 0$ (blockwork wall is airtight initially) $\Delta t_R = 0.5^oC$ Cost = Skr. $140/m^2$ Marginal cost for the insulation, since the work is carried out in conjunction with facade renovation.
Conversion of windows:	$\Delta U = 1.0\ W/m^{2o}C$ $\Delta t_R = 0.5^oC$ Cost = Skr. $300/m^2$ The windows are in perfect condition, and for this reason the whole cost is borne by energy conservation.

When the energy balance after the measures is calculated, Method B in Section 3.13 is used for calculation of the annual degree hour factor Q.
According to this, $Q' = 125\ 000^oCh$.

Assumption for the economic calculations:

Discount rate = 6%
Rise in price of energy: q = 6% over the first five years, after that q = 2%.

Service life T:

Structural measures T = 30 years
Installation engineering measures T = 15 years
but replacement of burner T = 10 years.

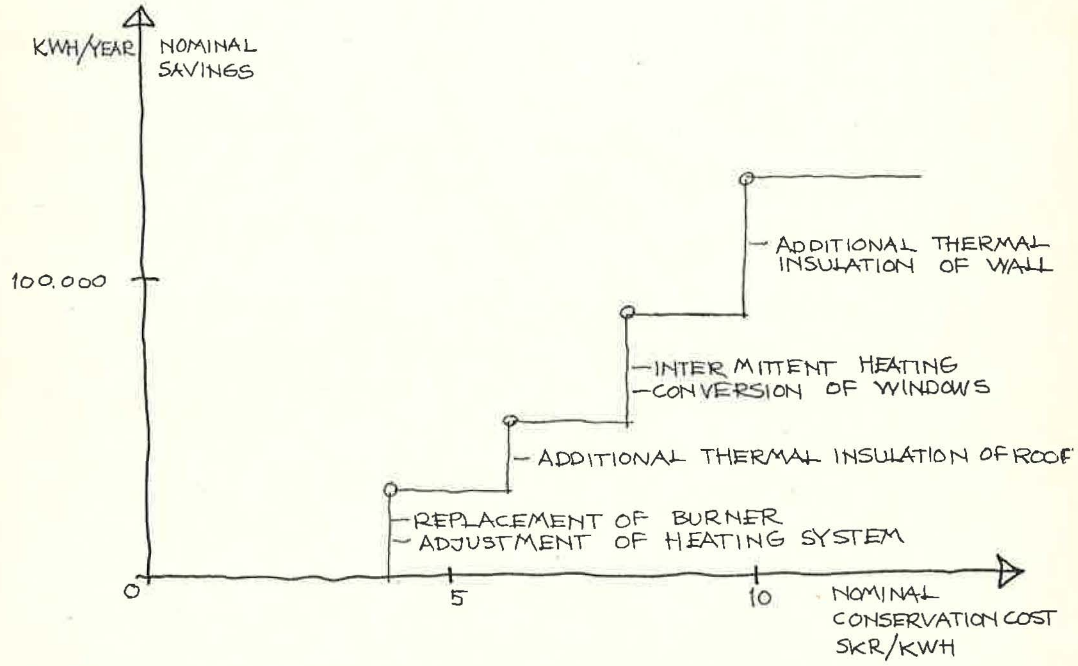
Results:

A) Energy consumption before the measures:

298 000 kWh annually

40 litres oil/m^2 annually

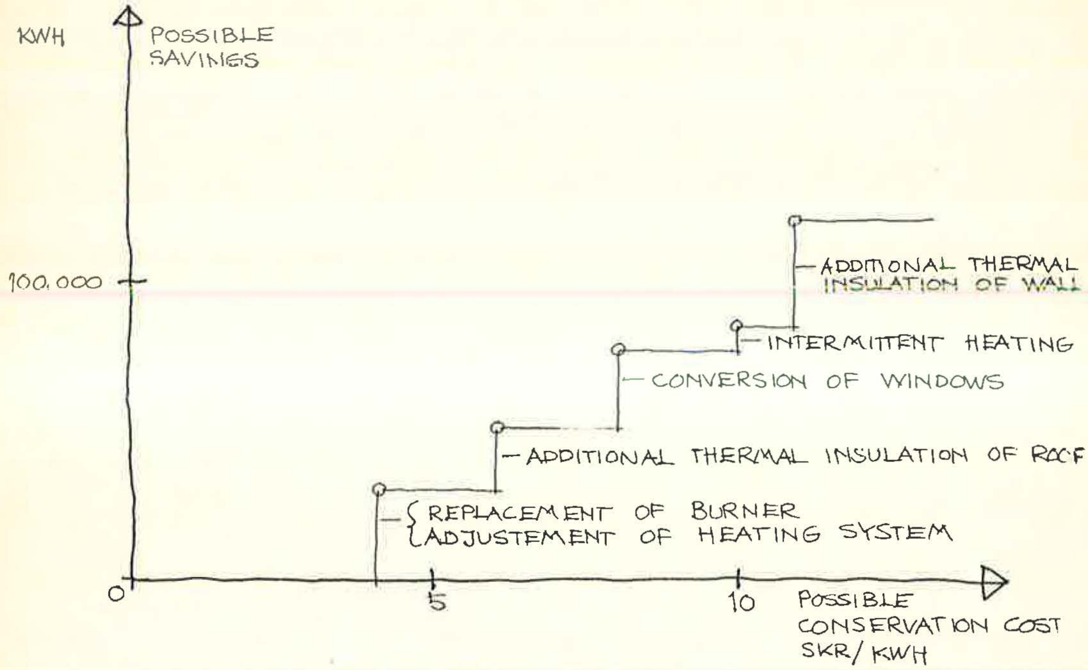
B) Nominal savings.



The nominal savings due to the measures, ranked according to conservation cost, are set out below.

Measure	nominal saving kWh	nominal conservation cost Skr/kWh
Adjustment of heating system	7 000	0.04
Replacement of burner	22 000	0.04
Additional thermal insulation of roof	21 000	0.06
Conversion of windows	30 000	0.08
Intermittent heating	7 000	0.08
Additional thermal insulation of wall	44 000	0.10

C) Possible savings.



Measure	possible saving kWh	possible conservation cost Skr/kWh
Adjustment of heating system	7 000	0.04
Replacement of burner	21 000	0.04
Additional thermal insulation of roof	19 000	0.06
Conversion of windows	27 000	0.08
Intermittent heating	5 000	0.10
Additional thermal insulation of wall	38 000	0.11

Comments:

When the results of the two methods of calculating savings are compared, it is seen that the effect is steeply reduced for measures with a higher conservation cost. For instance, the nominal saving due to additional insulation of wall is 44 000 kWh, but the actual saving is only 38 000 kWh.

In this case, at the current price level af about Skr. 0.15/kWh, it is profitable to carry out all the proposed measures. The conservation potential is about 119 000 kWh or about 17 litres oil/m^2 and year, and the total investment is about Skr. 138 000. To this must be added the cost of scaffolding for new rendering of the external walls. If the cost of this is assumed to be about Skr. 150/m^2, there is an additional Skr. 83 000 which is charged to the maintenance account. This cost accrues whether or not any energy is saved.

If it decided to conserve energy without doing any major work to the facade and without disturbing the occupants, only some of the proposed measures are carried out, e.g.

Adjustment of the heating system
replacement of burner
additional thermal insulation
of roof
intermittent heating.

The saving due to such a combination is about 54 000 kWh for a conservation cost for the combination of Skr. 0.06/kWh and an investment of about Skr. 37 000. The saving is equivalent to about 7 litres oil/m^2 and year. Whether the measure "conversion of windows" is to be included must be decided on in each individual case.

4.22 Building with a facade NOT in need of renovation

It is easy to assess the effect of the above, since all the previous conditions with the exception of one still apply. In this calculation, the following will apply for additional insulation of the wall:

$\Delta U = 0.41\ W/m^{2\,o}C$ (as before)

$\Delta t_R = 0.5^oC$ (as before)

Cost = Skr. 300/m^2

This cost includes thermal insulation, scaffolding, rendering.

Results:

Measure	possible saving kWh	possible conservation cost Skr/kWh
Adjustment of heating system	7 000	0.04
Replacement of burner	21 000	0.04
Additional thermal insulation of roof	19 000	0.06
Conversion of windows	27 000	0.08
Intermittent heating	5 000	0.11
Additional thermal insulation of wall	38 000	0.24

Comments:

The ranking and conservation potential of the measures are not changed, as additional thermal insulation of wall had the highest conservation cost before. The conservation cost of additional thermal insulation of wall rises from the previous Skr. 0.11/kWh to Skr. 0.24/kWh. This means that this measure is not profitable at current energy price levels. Measures to be carried out on the facade will not come up for consideration until work is to be carried out on the facade for reasons other than energy conservation.

4.23 Variable conditions, sensitivity analysis

As mentioned before, the potential savings, the composition of the combination and its economy depend on the conditions exhibited by each individual building. It is therefore of interest to perform calculations on the basis of variable conditions.

The calculations are performed by determining the conservation cost of a certain measure for a basic value of the parameter which is to vary. This parameter is then given new values, one higher and one lower than the basic value. The appropriate conservation cost is calculated for these. Comparison of the change in conservation cost with the change in the parameter shows how sensitive the calculation is to the accuracy of input data for the parameter in question.

The calculation technique is exemplified with reference to the measure "additional thermal insulation of wall", carried out on the same building as that in Section 4.21.

The example is based on the following basic values of the parameters:

initial U-value = 0.7 $W/m^{2\,o}C$

extra thermal resistance = 2.0 $m^{2\,o}C/W$ at a cost of Skr. 140/m^2

change of air temperature indoors = - 0.5^oC

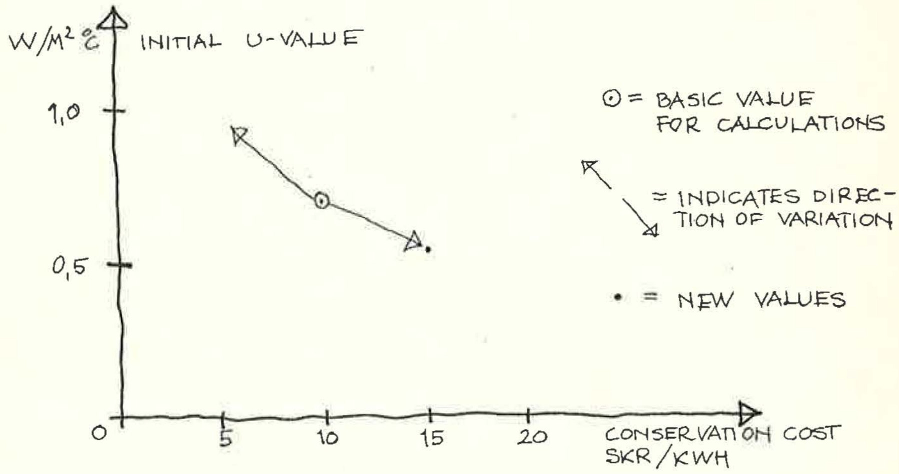
service life = 30 years

On the basis of these assumptions, the conservation cost = = Skr. 0.10/kWh for this measure.

We will now find by means of sensitivity analysis how important it is to know the correct initial U-value and how important it is that the indoor air temperature should be reduced.

The initial U-value is given one higher and one lower value than the basic value of 0.7 $W/m^{2o}C$. The higher value is made U = 0.9, and the lower one U = 0.5. The conservation cost of the measure is calculated for both these values, with the other parameters remaining at the basic values. The results of the calculations are set out in a diagram.

Variation in initial U-value.

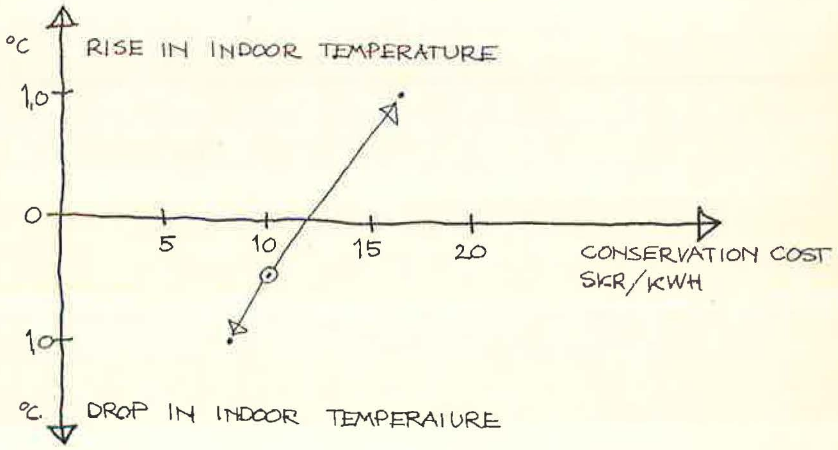


It is seen from the diagram that it is very important for the economy of the measure that the correct value of the thermal transmittance of the wall should be known before the measure. If too high a value is given, the insulation of the wall is poor and the measure is very profitable. If too low a value is given, the insulation of the wall is good and the measure verges on the unprofitable. The example demonstrates that it is essential to inspect buildings before measures are carried out, one of the things determined during the inspection being the functional U-value of the external walls with respect to moisture and infiltration of air.

In the basic calculation it was assumed that the indoor air temperature can be reduced by 0.5 °C. A reduction by 1.0 °C and an increase by 1.0 °C are investigated in the same way.

The results of the calculations are set out in the diagram below.

Alteration of indoor temperature.



It is seen from the diagram that the measure has the same good profitability as long as it is possible to lower the indoor temperature. The measure will not, however, be profitable if it results in the indoor temperature rising by 1.0°C. This demonstrates that a coupling between additional thermal insulation and temperature control is essential for a good energy conservation economy.

All the proposed measures can be investigated in the above manner for all buildings under consideration. In order to limit calculations, the sensitivity analysis should be applied especially to those parameters whose values are the most uncertain. The final results of the calculations can then be given in the form of a range within which the results of conservation measures should be situated.

4.3 Application of minisystem analysis to an office building

The office building has a heating and ventilation installation of relatively limited extent, and is not in need of facade renovation.

Input data for calculation of the energy balance before the measures:

Transmission losses $\Sigma(k_i A_i)$

External walls $U = 0.90\ W/m^{2\circ}C$

$A = 860\ m^2$

Basement walls	$U = 1.40\ W/m^{2\,o}C$
	$A = 350\ m^2$
Windows and doors	$U = 3.00\ W/m^{2\,o}C$
	$A = 400\ m^2$
Attic floor	$U = 0.45\ W/m^{2\,o}C$
	$A = 1\ 000\ m^2$
Ground floor	$U = 0.45\ W/m^{2\,o}C$
	$A = 1\ 000\ m^2$

Ventilation losses: $0.33\ n\ V_o$

Office premises	$n = 0.8$ ach
	$V_o = 8\ 100\ m^3$
Basement	$n = 0.3$ ach
	$V_o = 2\ 500\ m^3$

Hot water consumption 80 000 kWh.

Operational efficiency of own boiler $\eta = 75\%$.

Annual degree hour factor $Q = 103\ 000\ ^oCh$, and $+22^oC$ indoors.

Proposed measures, their effects and costs:

Replacement of burner:	$\Delta\eta = 5\%$ points
	Cost = Skr. 8 000
Adjustment of heating system:	
	$\Delta t_R = 0.5^oC$
	Cost = Skr. 7 500
Intermittent heating:	$\Delta t_R = 0.5^oC$
	Cost = Skr. 7 000
Adjustment of ventilation:	
(office premises)	$\Delta n = 0.1$ ach
	Cost = Skr. 6 000
Intermittent ventilation:	
(office premises)	$\Delta n = 0.15$ ach
	Cost = Skr. 15 000
Recovery of heat, ventilation:	
(office premises)	$\Delta n \doteq 0.20$ ach (100% recovery of heat from 0.20 ach)
	Cost Skr. 36 000

Additional thermal insulation of roof:	$\Delta U = 0.26\ W/m^{2o}C$
	Cost = Skr. $80/m^2$
Additional thermal insulation of wall:	$\Delta U = 0.58\ W/m^{2o}C$
	$\Delta n = 0.05$ ach
	Cost = Skr. $300/m^2$ (full cost)
Conversion of windows	$\Delta U = 1.0\ W/m^{2o}C$
	Cost = Skr. $300/m^2$

When the energy balance after the measures is calculated, Method B in Section 3.13 is used for calculation of the annual degree hour factor Q. According to this, $Q' = 125\ 000\ ^oCh$.

Assumptions for the economic calculations:

Discount rate: r = 6%
Rise in price of energy: q = 6% over the first five years, after that q = 2%.

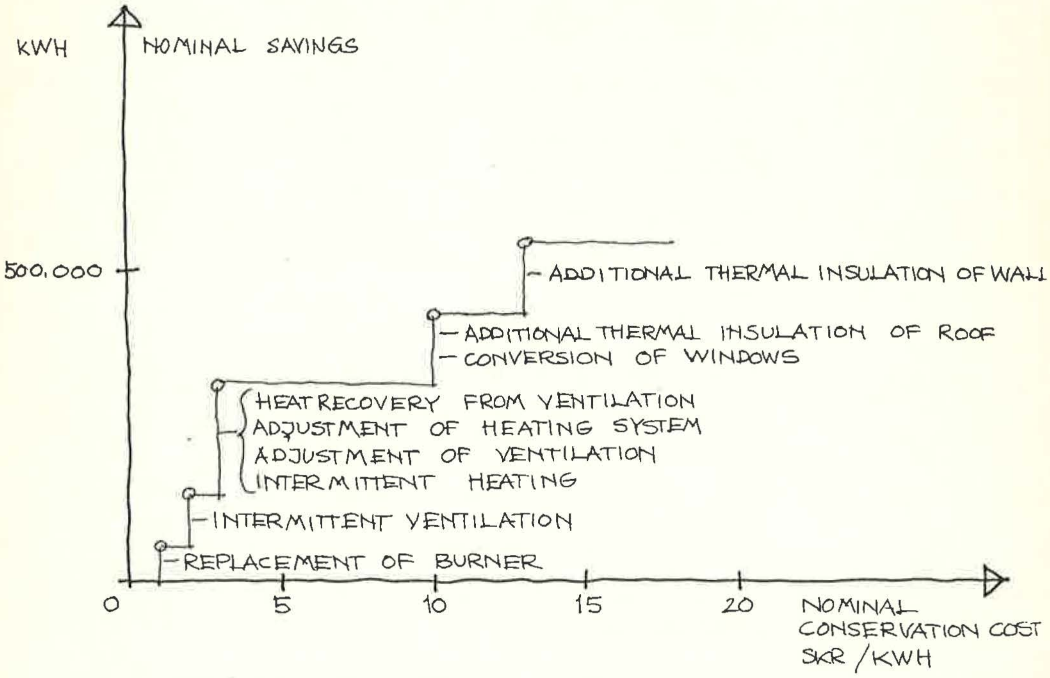
Service life T:

Structural measures	T = 30 years
Installation engineering measures	T = 15 years
but replacement of burner	T = 10 years
but adjustment of ventilation	T = 5 years

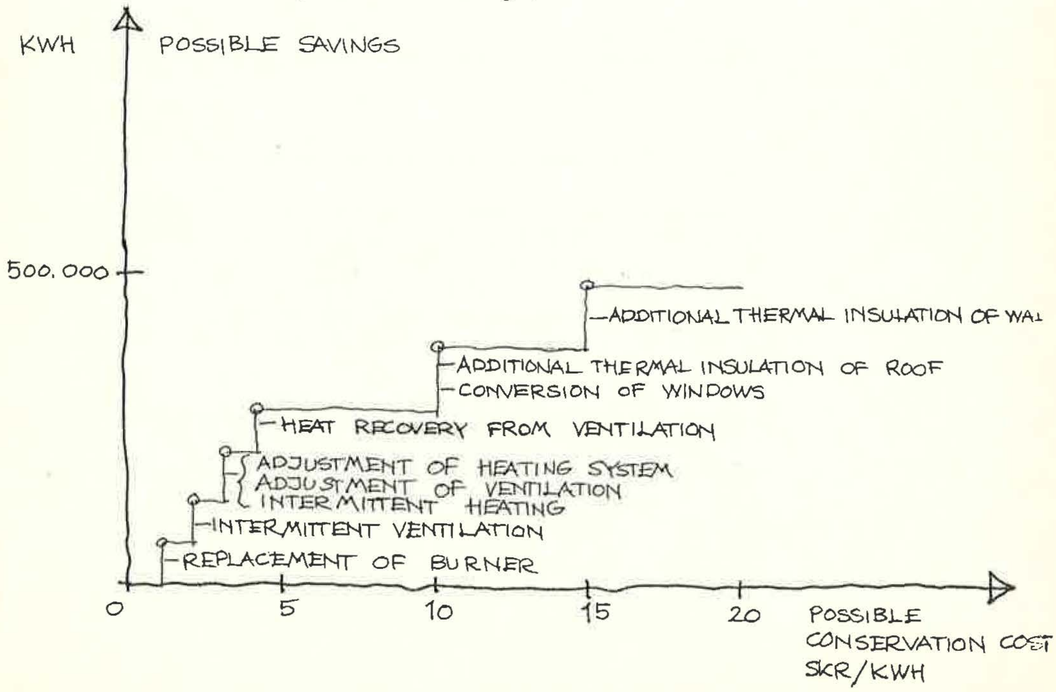
Results:

A) Energy consumption before the measures: 896 000 kWh annually.

B) Nominal savings.



C) Possible savings.



Measure	possible saving kWh	possible conservation cost Skr/kWh
Replacement of burner	66 000	0.01
Intermittent ventilation	63 000	0.02
Intermittent heating	20 000	0.03
Adjustment of ventilation	41 000	0.03
Adjustment of heating system	19 000	0.03
Recovery of heat from ventilation	80 000	0.04
Conversion of windows	60 000	0.11
Additional insulation of roof	39 000	0.11
Additional insulation of wall	94 000	0.15

Comments:

The proposed installation engineering measures exhibit excellent profitability and are ranked before the building measures. Owing to the fact that initially the building has very limited heating and ventilation equipment, the installation engineering measures are extensive.

The facades were considered not to be in need of renovation, and for this reason the measure additional thermal insulation of wall bears the full cost, i.e. facade cladding is also included in the calculation. This results in the conservation cost of this measure being high, verging on the unprofitable.

The composition of the combination of measures for this office building is different from the combination for the residential buildings, in as much as it is the installation engineering measures which are the most profitable, and it is also these which represent a large proportion of the conservation potential.

4.4 Some conclusions from the examples

The examples chosen show the way in which the method works. The measures which are proposed as a result of calculations are ranked according to their profitability up to present energy price levels. After this ranking has been done, different combinations of measures can be made up and studied on the basis of the required profitability and energy conservation targets.

Very far-reaching conclusions cannot be drawn from the figures in the selected examples, as these are based on assumptions concerning qualities and effects which exhibit considerable variation from building to building. There is a suggestion however that the composition of the packages differs in the three types of buildings. In single family houses it is the building measures which appear the most profitable, in blocks of flats the building and installation engineering measures seem to have about the same profitability, while in office buildings it appears that it is predominantly the installation engineering measures which are profitable.

In all the example, in order that the profitability attaching to additional thermal insulation of the facade may be satisfactory, this measure must be coupled with other work on the facade, so that the costs to be borne by the energy conservation account may be marginal. Such other work may, for instance, be facade maintenance.

Conversion of windows appears to merit inclusion in all combinations of measures. This measure does not appear to need coupling with other work on the facade, but can bear its full cost.

5. CONSEQUENCES OF ENERGY CONSERVATION IN THE FORM OF A COMBINATION OF MEASURES

The composition of the combination and the effect and economy of the savings made are determined by the properties of the building. The right combination must be found for the right building at the right time.

What is the right time is the most difficult to decide. Each constituent measure in a combination has its own right time. It is difficult to predict which of these times is the optimal one.

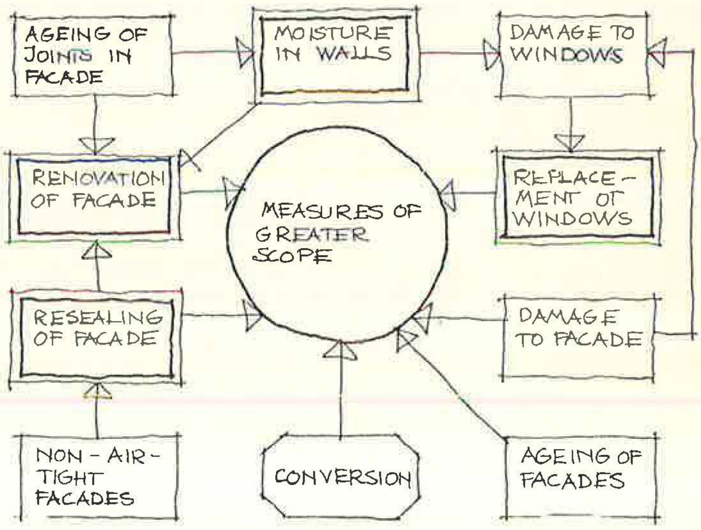
A combination may contain measures which should not, in actual fact, be carried out immediately but at a later date, It is found however that the extra expenditure due to bringing a measure forward can be taken into account in the calculations, with the result that, in spite of its being brought forward, the measure is so profitable that it should be included in a more comprehensive combination of measures.

The maximum calculated effect of a combination of measures may be reduced if the measures taken are not carried out in the right order and in the right way, or if the calculations had been based on far too optimistic assumptions concerning the effects of these measures. Obviously, the effect is also dependent on maintenance and attendance being performed in the normal manner.

Owing to economic optimisation, the combination of measures will be larger when it is applied in buildings which are in need of work for reasons other than purely energy conservation considerations, for instance alteration, renovation, maintenance, repair of damage or modernisation. In such situations the energy conservation measures are marginal, and their full cost is therefore not included in the calculations. As a result, it is mainly additional thermal insulation of external walls and replacement of windows which yield good economy. At the same time, these measures have a high conservation potential. One prerequisite is that access to capital is unlimited.

If energy conservation cannot be related to other work on the building, it is likely that the combination of measures will be smaller and will primarily concentrate on installation engineering measures. This is accentuated in buildings with comprehensive installations, such as offices.

The way in which work carried out on facades can be coupled with comprehensive energy conservation measures is set out in the figure below.



The following types of work can result in comprehensive energy conservation measures:

Conversion of building for technical or social reasons.
Work necessitated by ageing of facade, e.g. decay, loss of rendering, damage due to weathering.
Renovation of facade due to ageing of facade.
Ageing of facade wich causes moisture in the walls, which may result in window damage and replacement of windows.
Lack of airtightness in the facade which necessitates weatherproofing of facade.
Damage to windows which necessitates replacement of windows.

In the course of an inspection, it is therefore important to ascertain whether the building is in need of major work on the facade.

When the facade is damaged but not the windows, the energy conservation account will bear the marginal cost of facade insulation but the full cost of the windows. The cost of facade treatment and scaffolding will be borne by the maintenance account.

The situation is reversed if the windows are damaged but the facade is not. The windows will then be included at their marginal cost in the energy conservation account, while the insulation and surface treatment of the facade will be entered at their full cost. The cost of scaffolding and some of the costs for the windows will be charged to the maintenance account.

Calculations at combination level will then decide whether both the measures "additional thermal insulation of wall" and "windows", or only one of them, will be carried out.

This new method of approaching energy conservation in buildings in the form of a combination of measures necessitates changes in procedure, chiefly those carried out by public authorities.

Inspection.

In order that a sufficient and sound basis may be provided for an assessment of the composition of a combination, expert inspection is required. This shall establish the structural and energy status of the building. Structural examination must include an assessment of the present and future maintenance requirement of the climatic envelope, and the environmental considerations to be taken. Such an inspection requires competence in a number of areas. At present, there are not enough people who possess such wide-ranging competence. Inspection cannot therefore be carried out by one person, and inspection teams must be formed and trained if work on energy conservation is to begin soon. The involvement of a number of people may also result in other advantages, such as consultation.

Supervision.

When a combination of measures is carried out, the order in which the measures are done is important for an optimum result. The measures must be carried out in such a way that all potential conservation effects are made use of. Work therefore requires supervision which is capable of evaluating and coordinating techniques from several areas.

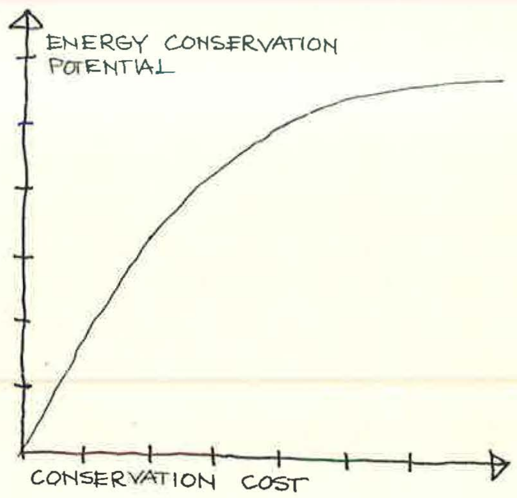
Information.

When a building has been subjected to an energy conservation process, the property manager, operational staff and the occupants must be supplied with the necessary information in order to ensure that the desired result is achieved and maintained during the remaining life of the building. Such information must thus be given not only in the beginning but must be repeated at intervals, so as to ensure that the requisite operational and maintenance measures are taken and that the achieved energy conservation is secured.

6. APPLICATION OF MINISYSTEM ANALYSIS AT MUNICIPAL LEVEL

Minisystem analysis has been employed in a current BFR project to develop models for the preparation of municipal energy conservation plans. The model has been applied in three municipalities in the west of Sweden, Stenungsund, Kungsbacka and Partille. BFR report R144:1980.

When the method is applied at municipal level, the housing stock is surveyed area by area and is grouped into building types. About 40 building types are usually sufficient. The energy characteristics for a certain area are determined by sample inspections. The energy conservation potential is then calculated for these building types as a function of the conservation cost. The results can then be scaled up area by area, due attention being paid to the distribution of building types in the areas, and the areas are summated for the municipality as a whole. The final results will take the form of a curve which shows the conservation potential as a function of the conservation cost. The shape of this curve will differ depending on the composition of the housing stock.



The curve shows the fundamental relationship between the energy conservation potential and conservation cost at municipal level.

7. APPLICATION OF MINISYSTEM ANALYSIS AT NATIONAL LEVEL

Minisystem analysis can be applied at national level in order that, on the basis of appropriate statistics, the available energy conservation potential may be scaled up and an assessment made.

The only appropriate statistics have been collected by the Swedish Institute for Building Research SIB. These are based on about 3 000 buildings whose energy characteristics were determined by means of inspections. This material can be scaled up by processing it in different ways, the composition of combinations of measures at building level being carried out in the manner described in the foregoing.
Two alternative approaches can be chosen,

Method A: composition of a combination for each building

Method B: composition of a combination for each building type.

A. Composition of a combination of measures for each building.

For each building in the statistics, an appropriate combination of measures is assembled, and the conservation potential of this calculated as a function of the conservation cost. The results are weighted and scaled up, and after summation the energy conservation potential for the country is obtained as a function of the conservation cost.

Design of the combination of measures for each building is performed on the basis of the data obtained during inspection, concerning

structural standard
installation engineering standard
need of facade renovation
cultural and historical aspects
any measures which have been carried out (1977).

Design takes place according to a formalised decision model which is based on the principles described in this investigation.

All processing according to Method A is performed in a computer.

B. Composition of a combination of measures for each building type.

In this method also, the SIB statistics concerning the national housing stock are made use of. The 3 000 buildings are grouped into a number of building types of similar energy standard.

For each of these building types, a combination of measures is assembled manually, due consideration being given to building and installation engineering standard and the maintenance needs of walls and windows.

The conservation potentials of the combinations of measures are calculated, and the energy conservation potential for the dwellings in the country is obtained by weighting and summation.