INTERNATIONAL ENERGY AGENCY
energy conservation in buildings and
community systems programme
Annex III
Residential Buildings Energy Analysis

Calculation Methods to Predict Energy Savings in Residential Buildings

Swedish Council for Building Research

This document is part of the work of the IEA Energy Conservation in Buildings and Community Systems Programme

Annex III Residential Buildings Energy Analysis

Participants in this task:

Belgium, Denmark, Italy, Netherlands, Sweden,
Switzerland, Turkey and the United States

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PREFACE

INTERNATIONAL ENERGY AGENCY

In order to strengthen cooperation in the vital area of energy policy, an Agreement on an International Energy Program was formulated among a number of industrialized countries in November 1974. The International Energy Agency (IEA) was established as an autonomous body within the Organization for Economic Cooperation and Development (OECD) to administer that agreement. Twenty-one countries are currently members of the IEA, with the Commission of the European Communities participating under special arrangement.

As one element of the International Energy Program, the Participants undertake cooperative activities in energy research, development, and demonstration. A number of new and improved energy technologies which have the potential of making significant contributions to our energy needs were identified for collaborative efforts. The IEA Committee on Energy Research and Development (CRD), assisted by a small Secretariat staff, coordinates the energy research, development, and demonstration program.

ENERGY CONSERVATION IN BUILDINGS AND COMMUNITY SYSTEMS

The International Energy Agency encourages research and development in a number of areas related to energy. In one of these areas, energy conservation in buildings, the IEA is encouraging various exercises to predict more accurately the energy use of buildings, including comparison of existing computer programs, building monitoring, comparison of calculation methods, etc. The difference and similarities among these comparisons have told us much about the state of the art in building analysis and have led to further IEA encouraged research.

ANNEX III RESIDENTIAL BUILDINGS ENERGY ANALYSIS

Energy conservation retrofits are in all IEA countries an important part of the energy saving plan. For the individual homeowner as well as for the nation as whole, it is vital that correct evaluations can be made of the energy saving potential of different retrofits. Since most of the analysis and installation of these retrofits are not done by architects and/or engineers, there is considerable concern that the retrofits will not be properly selected nor perform up to expectations.

All IEA countries need to develop for the marketplace simple, reliable calculation methods. The calculated recommendations then need to be applied in houses and tested for validity.

Recommendations may include new heating, ventilation and air-conditioning systems, new appliances, new insulating material, new glazings, etc. Because of the large number of possibilities of calculation types and recommended retrofits, international cooperation will accelerate the resolution of the problems involved.

The main problem, common to all, is how to generalize experimental results from time to time, place to place, on the national level. If this problem is solved findings in one country could also be used in another, and consequently extensive national research programs could be reduced and rationalized.

In order to generalize experimental results two things are needed: A reliable technique to observe and measure the conservation effect, and methods for converting these data to other environments. The main effort in Task III has therefore been made at finding the limitations and the best use of a number of calculation models that are currently used for predicting the energy consumption of dwellings (Subtask A), and at collecting and summarizing guiding principles concerning the design of experiments, instrumentation and measuring techniques (Subtask B). Finally the results of these two subtasks have been used when studying the energy conservation effect of a night-temperature setback in dwellings (Subtask C).

The participants in the Task are: Belgium, Denmark, Italy, the Netherlands, Sweden, Switzerland and the United States.

This report documents work carried out under subtask A of this task. The cooperative work and resulting report is described in the following section.

INTRODUCTION

The explicit purpose of this work was to find - if possible at all - a specific calculation method to recommend when predicting energy conservation in residential buildings and how the influence of inhabitants should be treated in different calculations.

The participants have used different calculation methods to predict energy consumption and energy savings by different conservation measures. The results of the calculations were compared with each other and in one case with measurements from a real building. The influence of inhabitants has turned up to be too great a task to handle in proper detail within this subtask. Some of the demands from the calculation methods and a Swiss investigation on the energy consumption in 60 similar houses has been discussed. It should also be noticed that the question of influence of inhabitants to a great extent has been investigated within the subtask covering guiding principles concerning design of experiments, instrumentation and measuring techniques.

The report has been prepared by the Lead Country in subtask A. In this preparation the analysts from the participating countries have given great support by attending analysts' meetings where different aspects of the report have been discussed in detail. The draft report has then been reviewed by the annex participants for approval.

The report is intended for both the non-expert as well as for the expert on calculation methods for energy consumption in buildings. For the non-expert the intention is to give an introduction to the field and give him a possibility to follow and use the more detailed analyses exhibited here. The benefits of this report is a better understanding of some calculation methods and their limitations in different situations. The report could thus be useful when selecting a calculation method to be used during generalization of the results from a specific energy conservation experiment.

Chapter 1 gives a brief introduction to the physical and numerical basis used in this field and chapter 2 gives a presentation of the investigated calculation methods. These were chosen to cover the most simple as well as the most complex methods in use. Chapters 3 and 4 describe the calculation cases which have been used for prediction of energy consumption and conservation. The calculation results are then analyzed in chapter 5 and chapter 6 gives the conclusions and recommendations. Chapter 7 covers the work carried out on influence of inhabitants.

The reader should note that this investigation is limited to a few examples of buildings and conservation measures, thus the result naturally is limited and the conclusions and recommendations should be read with care.

The major conclusions arising from work reported can be summarized as:

- For prediction of energy conservation, as well as energy consumption, the simplified methods seem to be as good as the more complex computer programs, as long as the method handles the free heat from internal and solar loads in a proper way.

- As the accessibility of the methods varies, and different types of retrofits do not always have their corresponding representation in the methods, the methods to be used when studying a specific retrofit have to be chosen from case to case.

The work carried out and reported under Annex I of the IEA implementing agreement on Energy Conservation in Buildings and Community Systems - Computer modelling of Building performance should also be reviewed to get a more general review of the state of the art of calculation methods.

Finally, I will express my acknowledgements to all analysts for their valuable contributions to the report, to Mr Arne Boysen, Operating Agent of Annex III, for his support during the work with the report and to the involved staff of the Department of Building Science for their kindly help.

1 BASIS FOR CALCULATION OF ENERGY CONSUMPTION AND SAVINGS IN RESIDENTIAL BUILDINGS

This chapter will give a brief overview of some basis for calculation of energy consumption in buildings. These basis will form a background for the description in the next chapter of the calculation methods investigated in this task. As we restrict ourselves to the heating of residential buildings, there will be no discussion about air conditioning systems.

If, for a moment, we disregard transitory heat storage in the building mass, the supplied energy is always equal to the energy losses (see Figure 1.1). This is also the situation if a longer period is studied as the storage heat then is neglected compared to the total losses.

The energy losses are of three types:

1 Transmission losses
2 Ventilation losses
3 Sewage losses

Transmission losses depend on the heat conduction through the building envelope. They can, as a simplification, be determined by multiplying the area by the U-value by the temperature difference. Ventilation losses depend on the ventilation rate and the temperature difference in the air entering and leaving the building. The sewage losses depend on the amount of water used in the building and the temperature difference of the water entering and leaving the building.

The total supplied net energy can be divided into four areas, namely

For the household (including domestic hot water)
For the heating system
From persons
From solar radiation

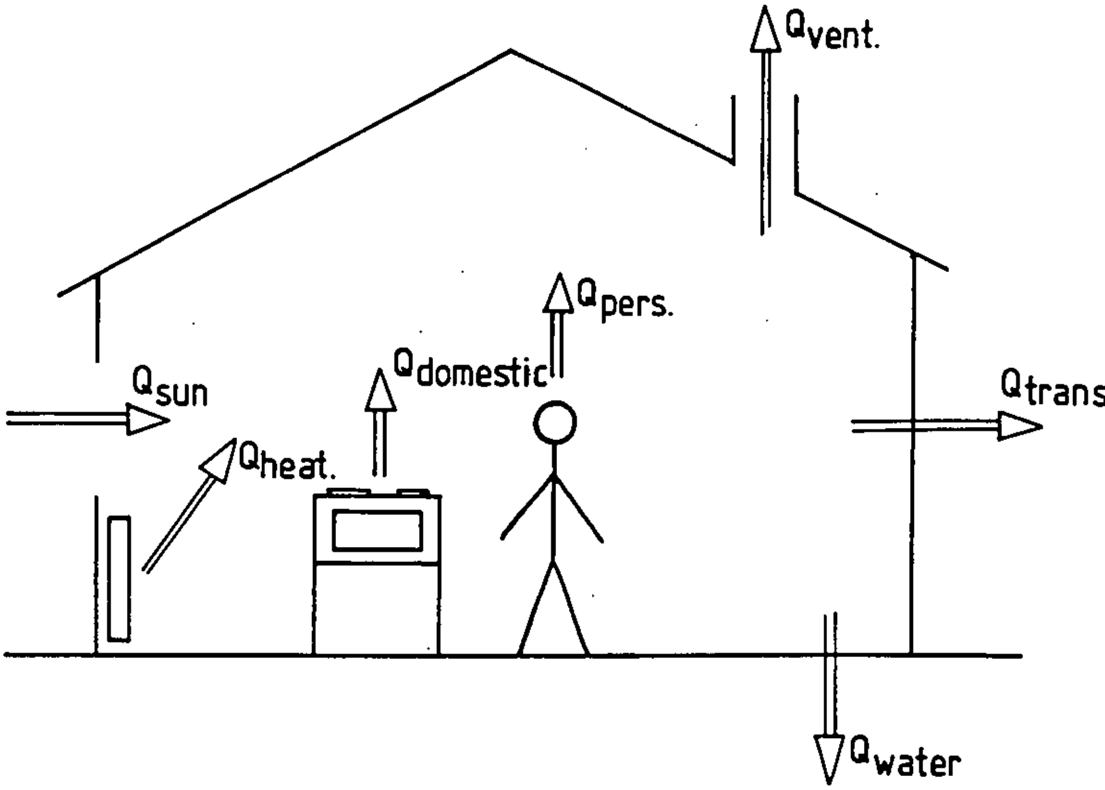

Figure 1.1 Schematic energy balance of a building.

Energy from persons and solar radiation is often referred to as free heat, but sometimes the household energy is also considered as free.

The calculation methods discussed in this report are restricted to calculation of energy losses by transmission and ventilation, thus neglecting the sewage losses. Furthermore, the calculation methods assume schedules for the energy from household and persons going to the room air and inner surfaces. Thus, these methods normally deal only with a part of the total energy balance of a building. Each method contains a more or less complex heat transfer model of the building.

For each part of a building, such as room air, room surfaces, walls, etc., a heat transfer equation can be given. These equations give, as a total system, the heat balance, or the heat transfer model, of a building. We will here give some examples of parts of such models, but have to leave out a lot of details. For more detailed studies of heat transfer, see e.g. F.Kreith, Principles of Heat Transfer (1965). More applied techniques can be studied in e.g. ASHRAE, Handbook of Fundamentals, 1981.

1.1 Heat balance of the room air

The heat balance of the room air is of major interest when discussing heating of a building. In most cases, heating is provided in order to maintain the room air at a minimum temperature level, the setpoint. If the room air tends to exceed this setpoint, the supply heat (in case of use of a room thermostat) will be cut off and the room temperature is an unknown variable in the problem. On the other hand, if the room air tends to drop below the setpoint, the temperature will be set to this point and the supply heat is the unknown variable. This discussion of a controlled heating system includes some approximations. In practice, a thermostat is sensitive to a combination of room air and inner surfaces' temperatures and the control of the supply heat is more or less accurate.

Normally there are variations in the room air temperature, e.g. close to the ceiling the air can be 3-4 ^{o}C warmer than close to the floor. In a model for energy calculation, this normally will be neglected and the room air temperature will be assumed uniform over the whole volume. Another common assumption is that all surfaces can be assumed isothermal. Under this condition, the heat balance for the room air can be written

$$C_R \frac{dT_R}{dt} = q_{free,conv} + q_{supply,conv} + c_p \cdot m_v (T_o - T_R) + \sum_i \alpha_{ci} A_i (T_i - T_R)$$

where

C_R = Heat capacity of room air
T_R = Room air temperature
t = Time
$q_{free,conv}$ = Convective, "free" energy to the room
$q_{supply,conv}$ = Convective supply energy to the room
c_p = Specific heat of air
m_v = Mass flow of ventilation and infiltration air
T_o = Outdoor air temperature
α_{ci} = Convective heat film coefficient for surface i
A_i = Area of surface i
T_i = Temperature of surface i

In many energy related calculations, the heat capacity of the room air can be neglected, thus giving a zero on the left side of the equation.

The equation indicates some questions, e.g.

- The convective "free" heat in residential buildings is mainly dependent on the individual use of the building. For an existing building the usage pattern e.g. the use of energy for cooking, domestic electricity, number of inhabitants present in the house during different hours of the day may be controlled or monitored. This usage pattern normally gives a reasonably accurate basis for the assumption of the free heat. For non-existing buildings a generalized usage pattern, based on broad studies, has to be used.

- The total ventilation is made up of two air flows, the infiltration and the ventilation. The infiltration is really a leakage through the building envelope due to temperature difference and wind pressure. The ventilation is,on the other hand, controlled by the inhabitants and due to window openings, the use of fans, etc. Therefore, a usage pattern has to be monitored or assumed.

- The convective heat film coefficients can be treated in many different ways and the literature normally gives a temperature dependent value in the format $\alpha_c=a(T_i-T_R)^b$, where a and b vary depending on which type of surface is involved. These constants are given different values by different authors. Min et al (1956) give, for example, a=0.14 and b=0.25 for a warm ceiling, while Davis and Griffith (1922) give a=1.31 and b=0.25 for the same kind of surface, a value almost ten times greater. This is an extreme example and for other types of surfaces the values normally are much closer to each other.

1.2 Heat balance for a surface

For each inner surface (or part of a surface), the following equation is valid:

$$q_{w,in}+q_{abs}+\alpha_{ci}(T_R-T_i)+\sum_j \alpha_{rij}(T_j-T_i)=0$$

where

$q_{w,in}$ = Heat flow from the wall to the inner surface
q_{abs} = Radiation absorbed on the surface

α_{ci} = Convective heat film coefficient
T_R = Room air temperature
T_i, T_j = Surface temperatures
α_{rij} = Radiative heat film coefficient between surface i and surface j

The radiation absorbed on the surface, mainly comes from two sources, internal sources and solar radiation. The internal sources are people, lighting, etc., which raises the same type of questions as already mentioned in the text concerning the heat balance of the room. The solar radiation will be discussed later and the convective heat film coefficient has been discussed above.

The radiative heat film coefficient depends on the geometry of the room, the emittance of the surfaces and their temperatures. These coefficients can be calculated for empty rooms assuming diffuse emittance on the surfaces. In reality, furniture, etc., will give deviations from the values for the empty room, but this is normally neglected.

The equation for inner surfaces is also valid for outer surfaces, but in this case the room air temperature is changed to the outdoor air temperature and the surrounding surfaces (T_j) are ground and sky. In this case, the convective heat film coefficient may be dependent on the wind speed at the surface.

1.3 Heat balance for a window

Figure 1.2 shows the principles of heat transfer for a double-glazed window. For the inner pane, following equation can be used:

$$q_{abs,2}+(\alpha_r+\alpha_c)(T_1-T_2)+\alpha_{ci}(T_R-T_2)+\sum_j \alpha_{r2j}(T_j-T_2)=0$$

where

$q_{abs,2}$ = Radiation absorbed in the inner pane, mainly solar radiation

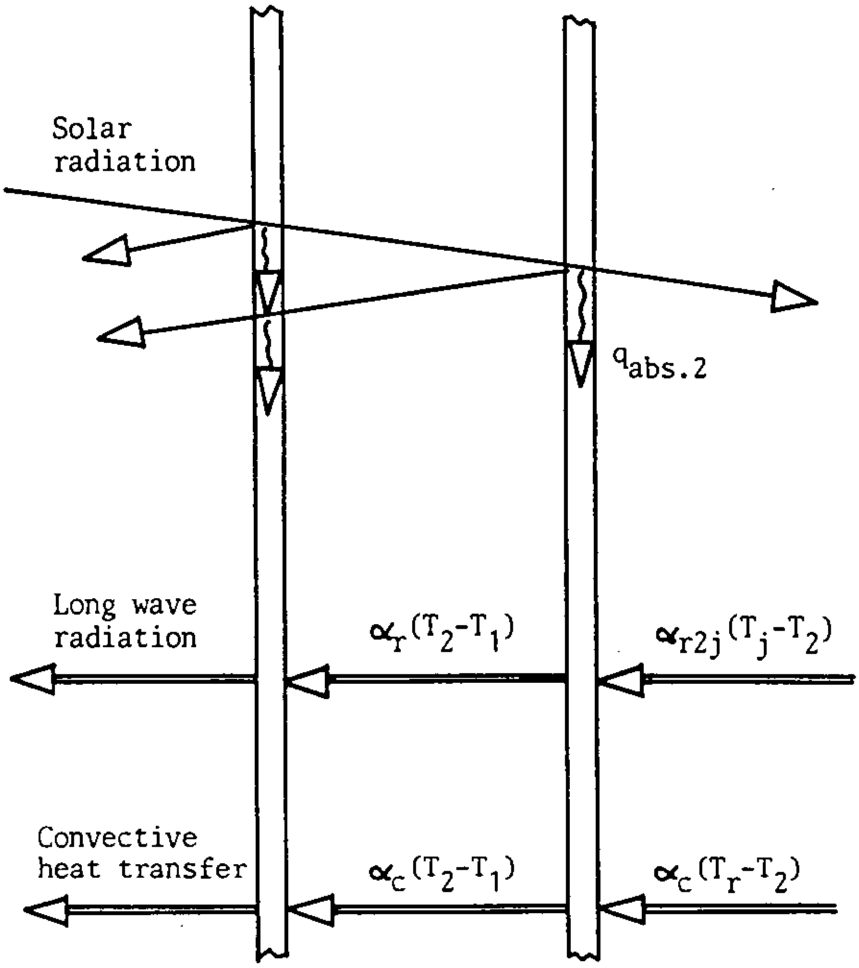

Figure 1.2 Heat balance of a window.

α_r = Radiative heat film coefficient between the panes

α_c = Convective heat film coefficient between the panes

T_1, T_2 = Temperature in pane 1 and pane 2

α_{ci} = Convective heat film coefficient on the inside of the window

T_R = Room air temperature

T_j = Temperature of inner surface j

α_{r2j} = Radiative heat film coefficient between inner pane and surface j

For the outer pane a similar equation can be used, but with the outdoor air, the ground and the sky as surround, as discussed for outer surfaces.

In the above equation, the heat capacity and the heat resistance of the pane are neglected. The earlier discussion on convective and radiative heat film coefficients is still valid. For the radiative film coefficient it is sometimes difficult to get proper data for odd types of coatings, films, etc.

In order to get a simplified model of a window, it is common to use constant values for all heat film coefficients and then by weighting according to the heat resistance, determine how much of the absorbed solar radiation goes into the room. The simplest model of the window is obtained by assuming the ground and sky temperatures as equal to the outdoor air temperature and all inner surface temperatures as equal to the room air temperature. These assumptions together with constant heat film coefficients give a U-value for the window.

A curtain or venetian blinds covering most of the window will change the heat balance of the window. In some cases they can be treated as another pane in the window, but with proper optical data. In a more exact analysis the air exchange between the space enclosed by the curtain and the room air should be considered.

The equation above gives the heat balance for the transparent part of the window. For the framing a U-value is normally assumed. Some window manufacturers give overall U-values for their windows. These include framing as well as the glazing and sometimes the air leakage as well. Such overall U-values are primarily intended for simplified calculations.

1.4 Heat transfer in walls and slabs

In this section we will briefly discuss some common ways to calculate one-dimensional heat flow in walls and slabs.

Steady state calculation

In cases where the heat capacity of the wall is neglected, the heat flow through the wall is described by the steady state equation

$$q = (T_1-T_2)/r$$

where

q = Heat flow
T_i = Surface temperature
r = Heat resistance of the wall

In more detailed models, the heat capacity in building parts must be taken into account.

In energy calculation methods the most common principles to treat unsteady state heat flow in walls are the finite difference methods and the response factor method.

Finite difference methods

The expression for one-dimensional heat conductions in solids is given by the Fourier equation

$$\frac{\partial T(x,t)}{\partial t} = a\,\frac{\partial^2 T(x,t)}{\partial x^2} \qquad \text{where } a = \frac{\lambda}{c\cdot\rho}$$

and

T = Temperature
t = Time
x = Length
a = Thermal diffusivity
λ = Thermal conductivity
c = Specific heat
ρ = Mass density

In order to solve the above equation we must convert the infinite differentials into finite differences. In the explicit method, the following approximation of the Fourier equation is used:

$$\frac{T(x,t+\Delta t)-T(x,t)}{\Delta t} = \frac{a}{(\Delta x)^2}\left\{T(x+\Delta x,t)+T(x-\Delta x,t)-2T(x,t)\right\}$$

Given the initial temperatures, the successive use of this difference equation gives the new temperatures step by step. The increments cannot be chosen arbitrarily, the expression $a\cdot\Delta t/(\Delta x)^2$ must be less than 0.5. In order to avoid this restriction other forms of differences can be chosen but then the method becomes implicit, requiring simultaneous solution of all temperatures. One example of an implicit method is the Crank-Nicholson's method using the following equation

$$\frac{T(x,t+\Delta t)-T(x,t)}{\Delta t} = \frac{a}{2(\Delta x)^2}\left\{T(x-\Delta x,t)+T(x+\Delta x,t)-2T(x,t)\right\} + \frac{a}{2(\Delta x)^2}\left\{T(x-\Delta x,t+\Delta t)+T(x+\Delta x,t+\Delta t)-2T(x,t+\Delta t)\right\}$$

Response factor method

The response factor method utilizes the fact that a wall can be characterized by the way it responds to a temperature pulse. A pulse causes a heat flow which varies with the time. For a "unit pulse" with given shape and size, the heat flow at different times is called the response factor for the wall. The response factors depend on the thermal properties and the dimensions of the wall. Methods to derive these factors can be found in many papers, e.g. Stephensen and Mitalas (1967) and Mitalas and Stephensen (1967).

A real temperature variation can be approximated as a sum of unit pulses and, following the superposition principle, the resulting heat flow can be calculated by adding the corresponding response factors.

The response factor method requires theoretically infinite series. In practice the summations must be truncated after a limited number of terms but even so, the amount of calculation work can be considerable. There exist, however, some methods to reduce the calculation work while maintaining an acceptable accuracy.

The Fourier-method (Heindl-Procedure)

This method assumes, that every thermal process in the building is represented by a series of harmonic functions in time, as

$$T(x,t) = \sum_k u(x)e^{iw_k t}$$

The Fourier equation reduces then for each frequency to

$$\frac{d^2u(x)}{dx^2} - iw_k \frac{\rho c}{\lambda} u(x) = 0$$

The solution of this equation can be represented by hyperbolic sine- and cosine functions. The advantage of the method is, that for the connection between the inside and outside temperatures u and heat fluxes $\dot{q}$ of a layer, a simple matrix representation can be found

$$\begin{pmatrix} u(D) \\ \dot{q}(D) \end{pmatrix} = \begin{bmatrix} \cosh(wD), \frac{1}{w}\sinh(wD) \\ w\cdot\sinh(wD), \cosh(wD) \end{bmatrix} \begin{pmatrix} u(0) \\ \dot{q}(0) \end{pmatrix}$$

with $w^2 = i w_k \lambda \rho c$

When a small construction is composed by different layers, the effective matrix can be found by multiplication of the matrices of the different layers.

The final solution of a problem can be found by superposition of the solutions of the partial frequencies. (Linearity of the Fourier-equation).

2- and 3-dimensional heat flows

The above discussion is limited to one-dimensional heat flow. In practice we have a lot of two- and three-dimensional heat flows in a building, for example around studs in a wall, in corners and in the foundations of buildings. To include a proper calculation of these types of heat flow in an energy consumption calculation would require too much computation work and large computers, thus making the calculation too expensive. In energy calculation methods we normally have to assume all walls and slabs to have only one-dimensional heat flow.

Heat transfer in ground

A detailed calculation of heat transfer in the ground around the foundation of a building is a rather elaborate task. In energy calculation methods, the foundation must be treated in a simplified way and normally, as mentioned above, with one-dimensional heat flow. However, by precalculated coefficients, two- or three-dimensional heat flow can be taken into account to some extent. Usually, a ground temperature, assumed according to experience, is used as the outside temperature experienced by the construction. Often the average outdoor temperature over a longer period is taken as the ground temperature.

1.5 Internal loads

Every method used to predict the energy consumption in a building must in some way predict the internal loads caused by the use of the building. In a residential building, the internal loads may be caused by occupancy, cooking, lighting, hot tap water, boilers, etc.

In principle every calculation method has to use schedules giving values and durations for all these loads. Necessary details in these schedules depend on how detailed the model used is, for example an hour-by-hour calculation must have hourly information while a method based on monthly periods might use average values.

Most of the internal loads are caused by the inhabitants and their use of equipments in the building. Subtask B of this annex has dealt with this question and the guide-lines produced by that group will give extensive details. (IEA Energy Conservation in Building and Community Systems, 1982).

1.6 Solar radiation

Solar heat gain is often an important part of free heat in a residential building and it is important to calculate this gain in an accurate way. However, detailed calculation of solar heat gain is rather elaborate and a lot of uncertain factors will influence the solar gain obtained in real buildings. In this paragraph, some of the phases in the calculation of solar heat gain will be briefly discussed. More detailed information can be found from the work of IEA Solar R&D. The report "An introduction to Meteorological measurements...." (1980) gives some basis and several references.

A common starting point is weather data giving direct solar radiation and diffuse sky radiation. These values have to be transformed into the total radiation indicent on the different surfaces of the building by taking into account solar angles, horizon angles, surrounding buildings, the shape of the target building and reflections from surrounding buildings and the ground.

If the absorptivity for the opaque surfaces of the building is known, the absorbed part of the radiation can easily be obtained and, in the total heat balance, used in the equations for the walls, etc.

In order to calculate transmission of solar radiation through windows, basic optical theory can be used for glass and thin layers. This requires basic physical data, such as refraction coefficients and absorptions in the glass mass. This type of data is sometimes difficult to get and one has to use simplified ways to treat the window.

One common way to describe solar transmission through a window is by the shading coefficient, which gives the ratio between the transmission for the window in question and a standard single-pane window. This ratio is normally assumed to be a constant and gives no possibility to examine how much solar radiation is absorbed in each pane.

Inside the room, the distribution of direct solar radiation is an elaborate geometrical problem, normally avoided by assuming only diffuse radiation in the room. The distribution of the diffuse radiation can be calculated assuming diffuse reflection in each inner surface of the room. In this case, the view factors have to be calculated and then combined with the reflectivity of the surfaces. Some calculation methods simplify this distribution according to the areas of the inner surfaces and some methods make the simplifying assumption that all or part of the transmitted solar radiation is a convective heat gain to the room air.

1.7 References

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2 INVESTIGATION OF CALCULATION METHODS

2.1 Classification of methods

Two main categories of methods to calculate annual energy consumption in buildings can be distinguished, namely simulation and correlation methods. Simulation methods are based on the solution of more or less detailed thermal models of the building in short timesteps, e.g. hour by hour. Correlation methods, on the other hand, give the energy consumption as a simple relation between the thermal losses of the building and mean weather data for longer periods.

The classification of the methods is summarized in the following figure.

- Dynamic Simulation methods
  - Thermal Balance methods
    - Finite differences
    - Response factors
    - Other methods
  - Weighting factor methods

- Correlation methods
  - Steady-state heat balance
  - Degree-day or corrected degree-day methods
  - Other correlation methods

Calculation of savings due to some conservation measure is normally carried out as a difference between two annual consumption levels. This implies that the method must be able to handle the measure in question with an accuracy great enough to use the difference between two annual consumption figures. On the other hand, error in some part of the calculation might equal out when taking the difference, thus in some cases a method can be more accurate when used to predict savings than when used to predict consumption.

Dynamic simulation methods

In simulation methods the thermal behaviour of the building is simulated step by step, usually with hourly intervals. This allows one to calculate the energy requirement and/or the room temperature, if the variable internal and external boundary conditions are known. Using weather-data for a whole year, the annual energy requirement then can be predicted. In addition, the simulation methods can be used with selected weather data for a "design-day" to size heating equipments.

Two common ways to carry out a simulation are the thermal balance method and the weighting factor method.

In the thermal balance method, the equation for all parts of a building, combined with the excitations due to internal loads, solar radiation and outdoor temperature give the total heat balance of a building. This balance can be described more or less complexly, depending on how many of the building parts are included in the thermal model. Thus, some methods only model the total building as a single space, while other methods take care of all heat transfer between rooms by modelling all rooms and all internal walls and slabs of the building.

The thermal balance method can be characterized by the numerical method used to treat the heat conduction in solids. As described in chapter 1, we can use finite difference methods, response factors, the Fourier-method or some other method.

The weighting factor method gives a different approach. Here we describe the heat requirement and/or room temperature as functions of the internal and external boundary conditions. (This is somewhat similar to the response factors for a wall). If these functions are known, the calculation work for each time-step is less than with the thermal balance methods. On the other hand, the output information cannot be so detailed as with the balance methods, particularly as far as the various temperatures are concerned. Moreover, the functions must be precalculated using a thermal balance model. Another restriction with weighting factor methods is that only linear systems can be treated; this can sometimes limit their usefulness.

Correlation methods

In some cases it is not necessary to know the very detailed trends of thermal parameters of the room, if overall results of energy requirements are sufficient. In these cases a correlation involving building characteristics and mean and/or overall climatic parameters, can be used to calculate the total energy requirement over a given period. Different complexity levels are possible, ranging from the well known "degree-day" method to more or less detailed methodologies for taking into account the utilization of "free energy" gains.

2.2 Simulation methods investigated

All the simulation methods involved in this investigation are computer programs working with one hour timesteps. Some of the main characteristics of these methods are summarized below.

	Size of thermal model	Main mathematical method	Includes air conditioning system
BA-4	Simple	Finite differences	No
NBSLD	Complex	Response factors	Yes
DYWON-2	Simple	Finite differences	No
KLIMASIM	Complex	Response factors	No
JULOTTA	Variable	Finite differences	No
DOE-II	Complex	Weighting factors	Yes

BA-4

This program handles one room or a whole building treated as a unit. The thermal network is reduced to one thermal capacity and four thermal resistances. The method is intended to give an inexpensive method for a full year simulation and is well suited for making special versions by adding subroutines.

Ref.: Hans Lund, BA-4 User's Guide, Thermal Insulation Laboratory, Denmark. Report No.44, 2 ed.,1979.

Hans Lund, The model and theory behind the BA-4 program, Thermal Insulation Laboratory, Internal report, 1977.

NBSLD

This program, original developed by National Bureau of Standards, US, uses a detailed heat balance model of each room in the building. One of the few simplifications in this program is the use of the shading coefficients when treating the windows.

Ref.: NBSLD: the computer program for heating and cooling loads in buildings, National Bureau of Standards, U.S., NBS-BSS 69, 1976.

DYWON-2

In this program the building is divided into a ground floor with one heat capacity, a single or double glazed window area, an opaque outer surface representing the external walls and roof with a weighted mean U-value and a heat capacity and the inner walls and slabs represented by a third capacitive construction. Radiative heat exchange is calculated by an approximating formula in which the ratio of the areas in question and the global shape of the building are taken as parameter values. The thermal balance is calculated each hour. The solar radiation on vertical surfaces is calculated with special subroutines.

Ref.: H.A.L.van Dijk, Basic study resulting from the revision of the Dutch requirements concerning thermal insulation of dwellings. Collected Papers of the 9th TVVL-TNO seminar, Delft, October, 1979.

H.A.L.van Dijk, Gebruiksbeschrijving computerprogramma DYWON, berekning van energieverbruik woningen. (User's guide computer program DYWON, calculation of energy consumption in dwellings), 2nd ed., internal report TPD, January 1982.

KLIMASIM

The calculation procedure concerned is based on calculating momentary events by solving heat balance equations for inside as well as for outside surfaces of each single room enclosure element, and for the room air in every single room. Dynamic heat transfer through the fabric of each enclosure element of different composition is represented by precalculated time series of response factors for temperature as well as for radiation excitation at the boundary. By applying convolution algorithms momentary events of temperature and heat flow at the surfaces are calculated. Room temperature deviations from the reference level of 20 °C in every single room are calculated by applying a weighting function concept, which includes the response of the entire room concerned. The weighting factors are precalculated.

Ref.: R.S.Soeleman, see Appendix A. (Documentation not published).

JULOTTA

JULOTTA is basically an RC-circuit analysis algorithm. This means that while the user must ordinarily manually create a network analog of the building to be simulated, JULOTTA gives him at the same time the ability to easily manipulate the network and to deal with a wide variety of different problems in extreme detail. The program has no Heating, Ventilating and Air Conditioning (HVAC) system modelling capabilities included; however, a special subroutine, SYSTEM, allows the user to build HVAC and control routines and access the simulation with appropriate alterations of modelling conditions while it is actually underway. The program also provides the user with routines for detailed calculation of shading, absorption and transmission of solar radiation in windows etc. In this subtask, the buildings have been represented in detail, modelling all convective film coefficients, radiative exchange in rooms and spaces between window-panes, etc. The heating system has been modelled in the above mentioned routine SYSTEM as a "perfect" controlled system.

Ref.: K.Källblad, F.Higgs, Building Energy Use Modelling in Sweden by JULOTTA, Proceedings of the Third International Conference on Energy Use Management, Berlin (West), October 26-30, 1981.

DOE-II

This public domain program was developed by Lawrence Berkeley Laboratories. The basic principles used in this program are the ASHRAE weighting factor methodology based on a rather complex thermal model of the building. The program uses an extensive Building Description Language to simplify the input preparation.

Ref.: M.Lokmanhekim, F.Winkelmann and A.Rosenfeld, DOE, A New State-of-the-art Computer program for the energy utilization analysis of buildings, The Third International Symposium on the Use of Computers for Environmental Engineering Related to Buildings, Banff, Canada, May 10-12, 1978.

2.3 Correlation methods investigated

Common to all correlation methods involved in this subtask is a steady-state calculation of transmission losses through the building envelope. For ventilation losses mean values for a particular time-base are used and none of the methods include any type of air conditioning system.

The main characteristics of the methods are summarized in the following.

	Required calculation equipment	Time-base for weather data
LPB-4	Computer	Week
EFB-1	Pocket-calculator	Month
SMECC	Pocket-calculator	Month
NEVACA	Pocket-calculator	Month
Degree-Day	-	Year
BKL	Pocket-calculator	Month
JAENV	Computer	Day

LPB-4

The heat gains in this method are assumed to be totally convective to the room air. The boundary conditions for the outer surfaces are the solar air temperatures, thus taking into account solar radiation on outer surfaces. All meteorological data are processed by another program on hourly basis, taking shading etc. into account. A fixed temperature for the ground is used.

Ref.: F.Lorenz, Static computation of thermal loads, Technical report E.E.C./78.12/A2 TC01 Contract No.615-78-1 EEB, University of Liège, 1978.

J.Lebrun, Y.Delorme, Données climatiques utilisables pour le calcul des charges thermiques appliquées aux bâtiments, Laboratoire de Phisique du Bâtiment, University of Liège.

EFB-1

The method uses monthly mean temperatures and monthly solar radiation through actual windows in a room or building. It can take into account the radiation on outside walls and roof, however, that is normally not done. Two extremes are calculated, the energy consumption for a "heavy" building where all "free" heat is utilized if needed and for a "light-weight" building where only a fraction of the "free" heat is utilized. Other buildings with the same heat losses are then computed by interpolation between the results for the extremes in each month.

Ref.: A.Nielsen, *A method for calculating the energy* consumption by means of a desk calculator, CIB Symposium, Copenhagen, May 28 - June 1, 1979. Thermal Insulation Laboratory, report no.81, 1979.

SMECC

Even this method uses the solar air temperature approach for outer opaque surfaces and precalculated values for shading of windows. "Free heat gains" are taken into account by means of a "coefficient of utilization" as a function of suitable "average" overall heat transfer coefficient, the mass of the building per unit floor area and the ratio between overall losses and overall gains. This function has been determined by a lot of parametric runs with the NBSLD-program.

Ref.: L.Agnoletto, P.Brunello, R.Zecchin, Simple methods for predicting thermal behaviour and energy consumption of buildings, ASHRAE-DOE Conference, Orlando, Florida, U.S., 1978.

NEVACA

For outer opaque surfaces the solar air temperature is used and solar gain on outer surfaces and through windows should be given (including shading) for clear days of each month. The monthly free heat is calculated from the number of clear and cloudy days, where the cloudy days are assumed to give 25% of solar gain compared with clear days. Days which are neither clear nor cloudy are assumed to give 65%. The losses are calculated by use of the monthly mean temperature. All solar and internal gains are assumed to be fully utilized.

Ref.: A-C.Andersson, Enkel metod för beräkning av värmebalans i byggnader, *Rapport NBH-7040, Department of Building* Technology, Lund Institute of Technology, 1978.

Degree-Day

The Degree-Day method used in this investigation has been based on the Swedish definition of degree-days. These are based on an indoor temperature of 17 °C and on a heating season defined by days with daily mean outdoor temperature below 17 °C during November-March and 12, 10, 10, 10, 11, 12 and 13 °C for April-October. Other days are not included when the degree-days are calculated. The real mean indoor temperature is in fact somewhat higher, but the temperature step from 17 °C is achieved by the free heat. Of course this temperature step in fact differs from situation to situation.

This method can (by definition) not handle conservation measures such as night temperature setback. Still, this report shows results for this method, which has been carried out by recalculating the degree-days for an indoor temperature lower than 17 °C.

BKL

This method uses daily solar radiation data, but by giving these in a simplified way, the energy requirement can be calculated month by month. The method neglects solar radiation on outer opaque surfaces. By the use of precalculated transmission coefficients for different oriented and shaded windows, the solar gain through windows can be estimated. The heat losses are calculated by the use of the monthly mean outdoor temperature. By comparing these losses with the distribution of "free heat", the monthly energy requirement for heating can be calculated.

Ref.: K.Källblad, B.Adamson, Hand calculation method for estimation of heat consumption in buildings, CIB Symposium, May 28 - June 1, 1979 in Copenhagen, Denmark.

JAENV

This method uses the solar air temperature approach to outer opaque surfaces. The transmission of solar radiation through windows can be defined in the input according to estimates for the individual case. To estimate the influence of shading, shading diagrams are used. Transmission losses are calculated for day- and night-time separately and the utilization of free heat is determined by the use of a utilization function which assumes decreasing utilization at increasing total heat gain. Required weather data for each day are mean outdoor temperature for day-time and nigth-time, total daily radiation on the horizontal and vertical planes in the 4 cardinal directions and the average wind speed for day. The latter is used to estimate infiltration.

Ref.: J.Gass, R.Sagelsdorff, Heizenergieverbrauch von Wohnbauten, EMPA 39200, February 1980.

3 CALCULATIONS FOR THE VETLANDA HOUSE

3.1 The house

The Swedish Association of Prefabricated Home Manufacturers built in 1975 a low energy one-family house in the town of Vetlanda, Sweden. The house (Figure 3.1) was designed by Bengt Hidemark, architect and professor at the Royal Institute of Technology, Stockholm, and professor Bo Adamson, Lund Institute of Technology, Lund.

The low-energy house has one storey, no basement, and was given quite an ordinary exterior at the request of the Association. The plan is shown in Appendix B. The floor area within the outer walls is 110 m^2. The house consists of three bedrooms, one living room, a dining room, a kitchen, a laundry, WC, and a bathroom including a sauna. The facade with the large windows faces 15^o east of south. On that facade the roof has an overhang of 1.8 m in order to shade the windows during the summer, when solar heat gain is undesirable. In the spring and autumn the altitude of the sun is so low that a considerable amount of insolation can be utilized for heating.

The windows in the south wall consist of four panes in sealed units. These windows cannot be opened, in contrast to the few other windows with only three panes, which can be opened. In the window wall facing south, the thermal insulation is not more than 95 mm. On the other hand, there are only small parts which are not windows or doors. As only a few of the windows are openable and as a well-insulated door is much better than a window with respect to both insulation and speedy airing, the low-energy house has six external doors. These doors will during the summer provide an easy and good contact between the house and the garden.

The other walls have a thermal insulation of 190 mm mineral wool. Below the concrete floor slab (160 mm), the floor is insulated with 120 mm mineral wool of a heavy quality. The thermal insulation in the ceiling is 300 mm of mineral wool.

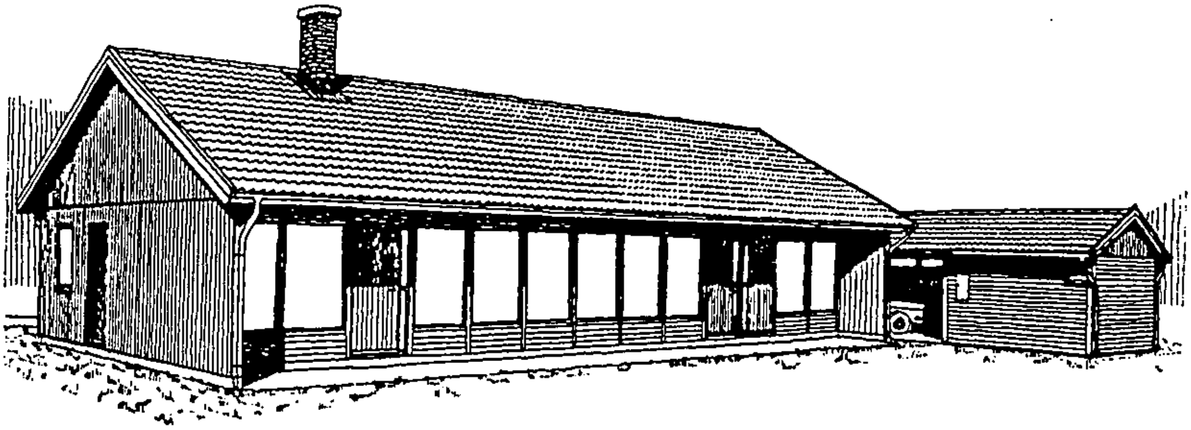


Figure 3.1 The Vetlanda house.

The ventilation is mechanical, with fans both to supply and exhaust air. The ventilation is divided into two parts. The bedrooms and the living room are continuously supplied with 20 and 40 m^3/h fresh air, respectively. The used air is exhausted from the kitchen, bathroom and WC. If more fresh air is needed in the living room, dining room or kitchen, one can push a button in any of the rooms, which results in a fresh air supply of 250 m^3/h total. This forced ventilation is on for a short period, for exemple 15 minutes, and then automatically cuts off. If further forced ventilation is needed, one has to push the button once again. The air supplied is preheated to 16 ^{o}C whenever the outdoor air temperature is lower than this level.

The building has been monitored for almost two years, but for this study we have selected a 6-month period with well controlled conditions. This enables comparisons not only between calculation methods but also to some extent between estimated and measured energy consumption. During the monitored period the building was not occupied, thus avoiding the influence of inhabitants. However, some simple occupancy patterns were simulated by use of time controlled electrical heat sources.

3.2 Calculation cases

The detailed specifications of the building used for the calculations are given in Appendix B. These were made as close as possible to the real building to get a good comparison. The weather tape produced for this task contains six months' data and Appendix C gives some of this data.

The study has covered six cases, namely the original case and five parametric studies. The details of these are described in Appendix B, and a short presentation of the main characteristics of the cases are given below.

The original case

The original building is used to enable comparison between predicted and measured energy consumption and together with the other cases to examine the different calculation methods' ability to handle various types of commonly used retrofits and of heat transfer phenomena.

Case (a)

In this case, all windows are assumed to have only two panes instead of three or four panes. The predicted consumption makes it possible to study changes in solar gains combined with changes in thermal insulation achieved by increasing the number of panes in the windows.

Case (b)

In this case the insulation in walls and ceilings is decreased compared to the original case. This case will, together with the original case, illustrate an increased insulation from a rather normal level to an extremely well insulated building. The U-values for this case and the original case are:

For the main walls: 0.57 and 0.23 $W/m^2,K$, respectively
For the ceiling: 0.40 and 0.14 $W/m^2,K$, respectively

Case (c)

This case differs from the original case by employing commonly used levels and times for night temperature setback from e.g. 20 °C to 16 °C between 22.00-06.00 hours all days of the week. (The setpoint for the preheater is not altered).

Case (d)

This case is a combination of the night temperature setback in case (c) and an insulation of the concrete floor by a carpet with a heat resistance of 1.0 m^2K/W. The insulation of the floor is thus increased and the heat capacity inside the house is decreased at the same time. This case was intended to show that the effect of the night time setback is potentially greater in lighter houses.

Case (e)

In this case the forced ventilation rate is increased from 100 m^3/h to 200 m^3/h. This allows a check of the ability of the calculation methods to handle ventilation losses.

3.3 Predicted energy consumption and savings

The monthly and total energy consumption predicted by the investigated methods are given in Tables 3.1 and 3.2a - 3.2e. The values include energy for the preheater as well as for the radiators. The setpoint of the preheater is 16 °C and some methods do not distinguish between preheating and the remaining heating of air by the radiators. Thus, these methods can normally only predict the total consumption. The degree-day method is one of these, but in this investigation an extra set of degree-days has been used by the analyst and hence the separation mentioned above was also possible in the degree-day method.

The predicted energy conservation, for all methods, is the difference between predicted energy consumption in case (a) - case (e) and the original case. These differences are given in Tables 3.3a - 3.3e.

The predicted energy consumptions and savings are further illustrated in chapter 5, where an analysis of the results is carried out.

Table 3.1 The Vetlanda House, orig. case, Heating Loads (MJ)

		NOV	DEC	JAN	FEB	MAR	APR	TOT
Preheater	Meas.	1464	1801	1801	1698	1413	1283	9460
	DD	1309	1905	1814	1750	1516	1270	9564
	EFB-1	-	-	-	-	-	-	-
	SMECC	1333	1952	1856	1789	1560	1305	9795
	NEVACA	1309	1905	1814	1750	1516	1290	9584
	BKL	-	-	-	-	-	-	-
	LPB-4	1330	1939	1851	1784	1550	1338	9792
	JAENV	1354	1968	1879	1810	1575	1319	9905
	BA-4	1326	1935	1846	1776	1536	1285	9704
	DYWON-2	1330	1941	1852	1780	1540	1288	9731
	DOE-2	1304	1900	1815	1747	1518	1269	9553
	JULOTTA	1317	1922	1834	1764	1526	1277	9640
	KLIMASIM	1326	1936	1848	1777	1538	1286	9711
Radiators	Meas.	5586	6791	6467	5157	3616	3862	31479
	DD	4808	6843	6558	6286	5547	4704	34746
	EFB-1	-	-	-	-	-	-	-
	SMECC	3673	6748	5915	5308	4015	3258	28917
	NEVACA	3551	5832	5106	4795	3357	2994	25635
	BKL	-	-	-	-	-	-	-
	LPB-4	3851	6157	5448	4923	3087	2238	25704
	JAENV	4245	6439	5832	5336	4145	3694	29691
	BA-4	3506	5590	4952	4483	3030	2844	24405
	DYWON-2	3070	5380	4762	4142	2675	2193	22222
	DOE-2	3288	5772	4907	4181	2300	1440	21888
	JULOTTA	4389	6927	6259	5881	4635	3817	31908
	KLIMASIM	3650	5041	4697	4222	3592	2852	24054
Total	Meas.	7050	8592	8268	6855	5029	5145	40939
	DD	6117	8748	8372	8036	7063	5974	44310
	EFB-1	5505	8257	7467	6878	5409	4881	38397
	SMECC	5006	8700	7771	7097	5575	4563	38712
	NEVACA	4860	7737	6920	6545	4873	4284	35219
	BKL	5510	8430	7780	7290	6020	5120	40150
	LPB-4	5181	8096	7299	6707	4637	3576	35496
	JAENV	5599	8407	7711	7146	5720	5013	39596
	BA-4	4832	7525	6798	6259	4566	4129	34109
	DYWON-2	4400	7321	6614	5922	4215	3481	31953
	DOE-2	4592	7672	6722	5928	3818	2709	31441
	JULOTTA	5706	8849	8093	7645	6161	5094	41548
	KLIMASIM	4976	6977	6545	5999	5130	4138	33765

Table 3.2a The Vetlanda House, Case (a), Heating Loads (MJ)

		NOV	DEC	JAN	FEB	MAR	APR	TOT
Preheater	DD	1309	1905	1814	1750	1516	1270	9564
	EFB-1	-	-	-	-	-	-	-
	SMECC	1333	1952	1856	1789	1560	1305	9795
	NEVACA	1309	1905	1814	1750	1516	1290	9584
	BKL	-	-	-	-	-	-	-
	LPB-4	1330	1939	1851	1784	1550	1338	9792
	JAENV	1354	1968	1879	1810	1575	1319	9905
	BA-4	1326	1935	1846	1776	1536	1285	9704
	DYWON-2	1330	1941	1852	1780	1540	1288	9731
	DOE-2	1304	1900	1815	1747	1518	1269	9553
	JULOTTA	1317	1922	1834	1764	1526	1277	9640
	KLIMASIM	1326	1936	1848	1777	1538	1286	9711
Radiators	DD	5923	8437	8087	7750	6843	5780	42820
	EFB-1	-	-	-	-	-	-	-
	SMECC	4883	8222	7436	6750	5411	4445	37147
	NEVACA	4679	7569	6648	6247	4458	4056	33657
	BKL	-	-	-	-	-	-	-
	LPB-4	4551	7370	6465	5837	3570	2610	30403
	JAENV	5643	8486	7713	7076	5564	4968	39450
	BA-4	4426	6972	6200	5630	3899	3670	30797
	DYWON-2	4056	6833	6084	5331	3610	3003	28917
	DOE-2	4399	7440	6356	5492	3289	2258	29234
	JULOTTA	-	8490	-	-	-	4703	39347
	KLIMASIM	4608	6445	5980	5369	4506	3556	30464
Total	DD	7232	10342	9901	9500	8359	7050	52384
	EFB-1	6542	9814	8878	8179	6444	5849	45706
	SMECC	6216	10174	9292	8539	6971	5750	46942
	NEVACA	5988	9474	8462	7997	5974	5346	43241
	BKL	-	-	-	-	-	-	48085
	LPB-4	5881	9309	8316	7621	5120	3948	40195
	JAENV	6997	10454	9592	8886	7139	6287	49355
	BA-4	5752	8907	8046	7406	5435	4955	40501
	DYWON-2	5386	8774	7936	7111	5150	4291	38648
	DOE-2	5703	9340	8171	7239	4807	3527	38787
	JULOTTA	-	10412	-	-	-	5980	48987
	KLIMASIM	5934	8381	7828	7146	6044	4842	40175

Table 3.2b The Vetlanda House, Case (b), Heating loads (MJ)

		NOV	DEC	JAN	FEB	MAR	APR	TOT
Preheater	DD	1309	1905	1814	1750	1516	1270	9564
	EFB-1	-	-	-	-	-	-	-
	SMECC	1333	1952	1856	1789	1560	1305	9795
	NEVACA	1309	1905	1814	1750	1516	1290	9584
	BKL	-	-	-	-	-	-	-
	LPB-4	1330	1939	1851	1784	1550	1338	9792
	JAENV	1354	1968	1879	1810	1575	1319	9905
	BA-4	1326	1935	1846	1776	1536	1285	9704
	DYWON-2	1330	1941	1852	1780	1540	1288	9731
	DOE-2	1304	1900	1815	1747	1518	1269	9553
	JULOTTA	1317	1922	1834	1764	1526	1277	9640
	KLIMASIM	1326	1936	1848	1777	1538	1286	9711
Radiators	DD	6584	9383	8881	8618	7595	6415	47476
	EFB-1	-	-	-	-	-	-	-
	SMECC	5386	9239	8317	7488	5863	4747	41040
	NEVACA	5638	8696	7854	7387	5625	4964	40164
	BKL	-	-	-	-	-	-	-
	LPB-4	5477	8452	7628	6961	3731	3034	35283
	JAENV	6289	9366	8571	7869	6222	5439	43756
	BA-4	5386	8230	7450	6830	4954	4455	37305
	DYWON-2	4962	8057	7261	6520	4537	3805	35142
	DOE-2	5745	9164	8123	7183	4767	3449	38431
	JULOTTA	-	9527	-	-	-	5347	46138
	KLIMASIM	5744	8090	7574	6878	5742	4559	38587
Total	DD	7893	11288	10695	10368	9111	7685	57040
	EFB-1	7715	11375	10375	9575	7606	6756	53402
	SMECC	6719	11191	10173	9277	7423	6052	50835
	NEVACA	6947	10601	9668	9137	7141	6254	49748
	BKL	-	-	-	-	-	-	53266
	LPB-4	6807	10391	9479	8745	5281	4372	45075
	JAENV	7643	11334	10450	9679	7797	6758	53661
	BA-4	6712	10165	9296	8606	6490	5740	47009
	DYWON-2	6292	9998	9113	8300	6077	5093	44873
	DOE-2	7049	11064	9938	8930	6285	4718	47984
	JULOTTA	-	-	-	-	-	-	55778
	KLIMASIM	7070	10026	9422	8655	7280	5845	48298

Table 3.2c The Vetlanda House, Case (c), Heating Loads (MJ)

		NOV	DEC	JAN	FEB	MAR	APR	TOT
Preheater	DD	1309	1905	1814	1750	1516	1270	9564
	EFB-1	-	-	-	-	-	-	-
	SMECC	-	-	-	-	-	-	-
	NEVACA	1309	1905	1814	1750	1516	1290	9584
	BKL	-	-	-	-	-	-	-
	LPB-4	1330	1939	1851	1784	1550	1338	9792
	JAENV	1354	1968	1879	1810	1575	1319	9905
	BA-4	1326	1935	1846	1776	1536	1285	9704
	DYWON-2	1330	1941	1852	1780	1540	1288	9731
	DOE-2	1304	1900	1815	1747	1518	1269	9553
	JULOTTA	1317	1922	1834	1764	1526	1277	9640
	KLIMASIM	1326	1936	1848	1777	1538	1286	9711
Radiators	DD	4277	6299	6013	5806	5016	4160	31571
	EFB-1	-	-	-	-	-	-	-
	SMECC	-	-	-	-	-	-	-
	NEVACA	3033	5288	4575	4316	2812	2475	22499
	BKL	-	-	-	-	-	-	-
	LPB-4	3299	5585	4876	4407	2516	1673	22356
	JAENV	3693	5840	5247	4815	3613	3174	26382
	BA-4	3208	5096	4469	4045	2600	2504	21922
	DYWON-2	2662	4911	4294	3720	2215	1779	19581
	DOE-2	2894	5226	4383	3716	1877	1109	19205
	JULOTTA	-	6499	-	-	-	3351	29373
	KLIMASIM	2660	4393	3822	3819	2858	2090	19642
Total	DD	5586	8204	7827	7556	6532	5430	41135
	EFB-1	-	-	-	-	-	-	-
	SMECC	-	-	-	-	-	-	-
	NEVACA	4342	7193	6389	6066	4328	3765	32083
	BKL	-	-	-	-	-	-	37538
	LPB-4	4629	7524	6727	6191	4066	3011	32148
	JAENV	5047	7808	7126	6625	5188	4493	36287
	BA-4	4534	7031	6315	5821	4136	3789	31626
	DYWON-2	3992	6852	6146	5500	3755	3067	29312
	DOE-2	4198	7126	6198	5463	3395	2378	28758
	JULOTTA	-	8421	-	-	-	4628	39013
	KLIMASIM	3986	6329	5670	5596	4396	3376	29353

Table 3.2d The Vetlanda House, Case (d), Heating Loads (MJ)

		NOV	DEC	JAN	FEB	MAR	APR	TOT
Preheater	DD	1309	1905	1814	1750	1516	1270	9564
	EFB-1	-	-	-	-	-	-	-
	SMECC	-	-	-	-	-	-	-
	NEVACA	1309	1905	1814	1750	1516	1290	9584
	BKL	-	-	-	-	-	-	-
	LPB-4	1330	1939	1851	1784	1550	1338	9792
	JAENV	1354	1968	1879	1810	1575	1319	9905
	BA-4	1326	1935	1846	1776	1536	1285	9704
	DYWON-2	1330	1941	1852	1780	1540	1288	9731
	DOE-2	1304	1900	1815	1747	1518	1269	9553
	JULOTTA	1317	1922	1834	1764	1526	1277	9640
	KLIMASIM	1326	1936	1848	1777	1538	1286	9711
Radiators	DD	4160	6130	5845	5638	4873	4044	30690
	EFB-1	-	-	-	-	-	-	-
	SMECC	-	-	-	-	-	-	-
	NEVACA	2877	5093	4380	4134	2644	2333	21461
	BKL	-	-	-	-	-	-	-
	LPB-4	3143	5429	4716	4262	2354	1528	21432
	JAENV	3693	5840	5247	4815	3613	3174	26382
	BA-4	3111	5040	4437	4023	2651	2399	21661
	DYWON-2	2484	4654	4053	3492	2040	1618	18341
	DOE-2	2739	5013	4182	3531	1744	999	18208
	JULOTTA	-	6391	-	-	-	3277	28798
	KLIMASIM	2530	4262	3657	3606	2695	1899	18649
Total	DD	5469	8035	7659	7388	6389	5314	40254
	EFB-1	-	-	-	-	-	-	-
	SMECC	-	-	-	-	-	-	-
	NEVACA	4186	6998	6194	5884	4160	3623	31045
	BKL	-	-	-	-	-	-	36880
	LPB-4	4473	7368	6567	6046	3904	2866	31224
	JAENV	5047	7808	7126	6625	5188	4493	36287
	BA-4	4437	6975	6283	5799	4187	3684	31365
	DYWON-2	3814	6595	5905	5272	3580	2906	28072
	DOE-2	4043	6913	5997	5278	3262	2268	27761
	JULOTTA	-	8313	-	-	-	4554	38438
	KLIMASIM	3856	6198	5505	5383	4233	3185	28360

Table 3.2e The Vetlanda House, Case (e), Heating Loads (MJ)

		NOV	DEC	JAN	FEB	MAR	APR	TOT
Preheater	DD	2462	3603	3434	3305	2890	2398	18092
	EFB-1	-	-	-	-	-	-	-
	SMECC	2405	3521	3348	3227	2813	2355	17669
	NEVACA	2462	3603	3434	3305	2890	2398	18092
	BKL	-	-	-	-	-	-	-
	LPB-4	2504	3650	3484	3358	2918	2519	18433
	JAENV	2547	3701	3534	3405	2963	2482	18632
	BA-4	2506	3654	3487	3362	2929	2440	18378
	DYWON-2	2514	3665	3499	3371	2928	2447	18424
	DOE-2	2608	3800	3630	3495	3036	2537	19106
	JULOTTA	-	-	-	-	-	-	18176
	KLIMASIM	2506	3653	3488	3361	2920	2450	18378
Radiators	DD	4873	6895	6610	6350	5599	4756	35083
	EFB-1	-	-	-	-	-	-	-
	SMECC	3957	7054	6220	5581	4310	3542	30664
	NEVACA	3849	6130	5404	5067	3629	3292	27371
	BKL	-	-	-	-	-	-	-
	LPB-4	4063	6376	5666	5121	3306	2443	26975
	JAENV	4548	6767	6152	5621	4440	3981	31509
	BA-4	3832	5926	5289	4791	3363	3167	26368
	DYWON-2	3399	5718	5103	4453	3012	2507	24192
	DOE-2	3459	5910	5033	4299	2390	1565	22656
	JULOTTA	-	-	-	-	-	-	33477
	KLIMASIM	3976	5377	5044	4526	3928	3178	26029
Total	DD	7335	10498	10044	9655	8489	7154	53175
	EFB-1	6928	10197	9347	8673	6945	6210	48300
	SMECC	6362	10575	9568	8808	7123	5897	48333
	NEVACA	6311	9733	8838	8372	6519	5690	45463
	BKL	-	-	-	-	-	-	50685
	LPB-4	6567	10026	9150	8479	6224	4962	45408
	JAENV	7095	10468	9686	9026	7403	6463	50141
	BA-4	6338	9580	8776	8153	6292	5607	44746
	DYWON-2	5913	9383	8602	7824	5940	4954	42616
	DOE-2	6067	9710	8663	7794	5426	4102	41762
	JULOTTA	-	-	-	-	-	-	51653
	KLIMASIM	6482	9030	8532	7887	6848	5628	44407

Table 3.3a Energy Conservation in Case (a), (MJ)

	NOV	DEC	JAN	FEB	MAR	APR	TOT
DD	1115	1594	1529	1464	1296	1076	8074
EFB-1	1037	1557	1411	1301	1035	968	7309
SMECC	1210	1474	1521	1442	1396	1187	8230
NEVACA	1128	1737	1542	1452	1101	1062	8022
BKL	-	-	-	-	-	-	7935
LPB-4	700	1213	1017	914	483	372	4699
JAENV	1398	2047	1881	1740	1419	1274	9759
BA-4	920	1382	1248	1147	869	826	6392
DYWON-2	986	1453	1322	1189	935	810	6695
DOE-2	1111	1668	1449	1311	989	818	7346
JULOTTA	-	-	-	-	-	-	7439
KLIMASIM	958	1404	1283	1147	914	704	6410

Table 3.3b Energy Conservation in Case (b), (MJ)

	NOV	DEC	JAN	FEB	MAR	APR	TOT
DD	1776	2540	2323	2332	2048	1711	12730
EFB-1	2210	3118	2908	2697	2197	1875	15005
SMECC	1713	2491	2402	2180	1848	1489	12123
NEVACA	2087	2864	2748	2592	2268	1970	14529
BKL	-	-	-	-	-	-	13116
LPB-4	1626	2295	2180	2038	644	796	9579
JAENV	2044	2927	2739	2533	2077	1745	14065
BA-4	1880	2640	2498	2347	1924	1611	12900
DYWON-2	1892	2677	2499	2378	1862	1612	12920
DOE-2	2457	3392	3216	3002	2467	2009	16543
JULOTTA	-	-	-	-	-	-	14230
KLIMASIM	2094	3049	2877	2656	2150	1707	14533

Table 3.3c Energy Conservation in Case (c), (MJ)

	NOV	DEC	JAN	FEB	MAR	APR	TOT
DD	531	544	545	480	531	544	3175
EFB-1	-	-	-	-	-	-	-
SMECC	-	-	-	-	-	-	-
NEVACA	518	544	531	479	545	519	3136
BKL	-	-	-	-	-	-	2612
LPB-4	552	572	572	516	571	565	3348
JAENV	552	599	585	521	532	520	3309
BA-4	298	494	483	438	430	340	2483
DYWON-2	408	469	468	422	460	414	2641
DOE-2	394	546	524	465	423	331	2683
JULOTTA	-	-	-	-	-	-	2535
KLIMASIM	990	648	875	403	734	762	4412

Table 3.3d Energy Conservation in Case (d), (MJ)

	NOV	DEC	JAN	FEB	MAR	APR	TOT
DD	648	713	713	648	674	660	4056
EFB-1	-	-	-	-	-	-	-
SMECC	-	-	-	-	-	-	-
NEVACA	674	739	726	661	713	661	4174
BKL	-	-	-	-	-	-	3270
LPB-4	708	728	732	661	733	710	4272
JAENV	552	599	585	521	532	520	3309
BA-4	395	550	515	460	379	445	2744
DYWON-2	586	726	709	650	635	575	3881
DOE-2	549	759	725	650	556	441	3680
JULOTTA	-	-	-	-	-	-	3110
KLIMASIM	1120	779	1040	616	897	953	5405

Table 3.3e Energy Conservation in Case (e), (MJ)

	NOV	DEC	JAN	FEB	MAR	APR	TOT
DD	1218	1750	1672	1619	1426	1180	8865
EFB-1	1423	1940	1880	1795	1536	1329	9903
SMECC	1356	1875	1797	1711	1548	1334	9621
NEVACA	1451	1996	1918	1827	1646	1406	10244
BKL	-	-	-	-	-	-	10535
LPB-4	1386	1930	1851	1772	1587	1386	9912
JAENV	1496	2061	1975	1880	1683	1450	10545
BA-4	1506	2055	1978	1894	1726	1478	10637
DYWON-2	1513	2062	1988	1902	1725	1473	10663
DOE-2	1475	2038	1941	1866	1608	1393	10321
JULOTTA	-	-	-	-	-	-	10105
KLIMASIM	1506	2053	1987	1888	1718	1490	10642

4 CALCULATIONS FOR THE TEKNIKERN BUILDING

4.1 The building

This building is an 8-storey apartment building, typical for many parts of Sweden and northern Europe. Each storey has about 665 m^2 of living area. The walls are concrete sandwich-elements with 70 mm of insulation and the ceiling has 200 mm of insulation giving approximately a U-value of 0.49 $W/m^2,K$ for the walls and 0.19 $W/m^2,K$ for the ceiling. All windows have two panes and the building is equipped with an exhaust air ventilating system. The building is a hypothetical building and the specifications, given in Appendix B, are to a great extent simplified in order to avoid differences caused by analyst interpretation.

The main purpose for including this building in the comparisons between calculation methods is to study the different methods' capability to predict the yearly heating requirement of big residential buildings.

4.2 Predicted energy consumption

The energy consumption for heating has been predicted for a whole year using weather data from Stockholm 1971. The predictions of the different methods are given in Table 4.1 and will be further illustrated in connection with the analysis in chapter 5.

Table 4.1 The Teknikern Building, Total Heating Loads (GJ)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OKT	NOV	DEC	YEAR
DD	270	252	283	198	58	0	0	0	76	137	234	241	1749
EFB-1	169	152	167	87	23	11	4	7	27	57	133	143	980
SMECC	165	152	166	77	0	0	0	0	2	43	127	139	871
NEVACA	201	187	212	115	11	0	0	0	11	68	166	173	1144
BKL	170	153	175	77	0	0	0	0	2	13	137	143	870
JAENV	171	157	175	92	20	1	0	0	19	58	138	145	976
BA-4	157	146	163	74	5	0	0	0	4	39	124	132	844
DYWON-2	164	153	170	59	5	0	0	0	2	38	130	140	861
NBSLD	161	140	159	64	8	0	0	0	3	30	123	131	819
DOE-II	165	149	162	70	4	0	0	0	3	40	131	138	862
JULOTTA	162	150	161	68	4	0	0	0	4	41	121	137	848

5 ANALYSIS OF THE CALCULATION METHODS

5.1 Predictions of annual energy consumption

The predicted energy consumption of the original case of the Vetlanda house is shown in Figure 5.1 together with the measured value. In this figure, only five months have been selected as all methods showed great differences from the measurements during November 1976. This led to the discovery that the thermostats in the building were erroneously giving too high indoor temperature compared with the calculation specifications.

The differences from the measured value can depend on many things, e.g. the calculations are based on specifications which might not have been fulfilled in the real building, such as cold bridges, etc. If the calculation methods react in different ways to these deviations, the results will deviate from each other. This shows that a single energy consumption figure is definitely inadequate when one tries to verify a calculation method. To make a complete verification of a calculation method, many more parameters have to be monitored, thus giving a possibility to check all parts of the calculation. Even for a method which predicts a consumption close to the measured value, one cannot be sure that this is not a result of opposing errors.

From Figure 5.1 one can observe that the predicted energy consumption varies around the measured value. The relation between the highest and lowest prediction is 1.43 to 1.0. Looking at case (b) of the Vetlanda house (decreased insulation) as shown in Figure 5.2, the same variation is only 1.27 to 1.0.

The observation of the ratio between the highest and lowest prediction might indicate a problem with the handling of free heat from people and solar radiation and its utilization for heating. This free heat becomes less important when the losses are greater, thus the smaller ratio in case (b). This indicates the need of a deeper analysis of how the free heat is taken into account in the different methods.

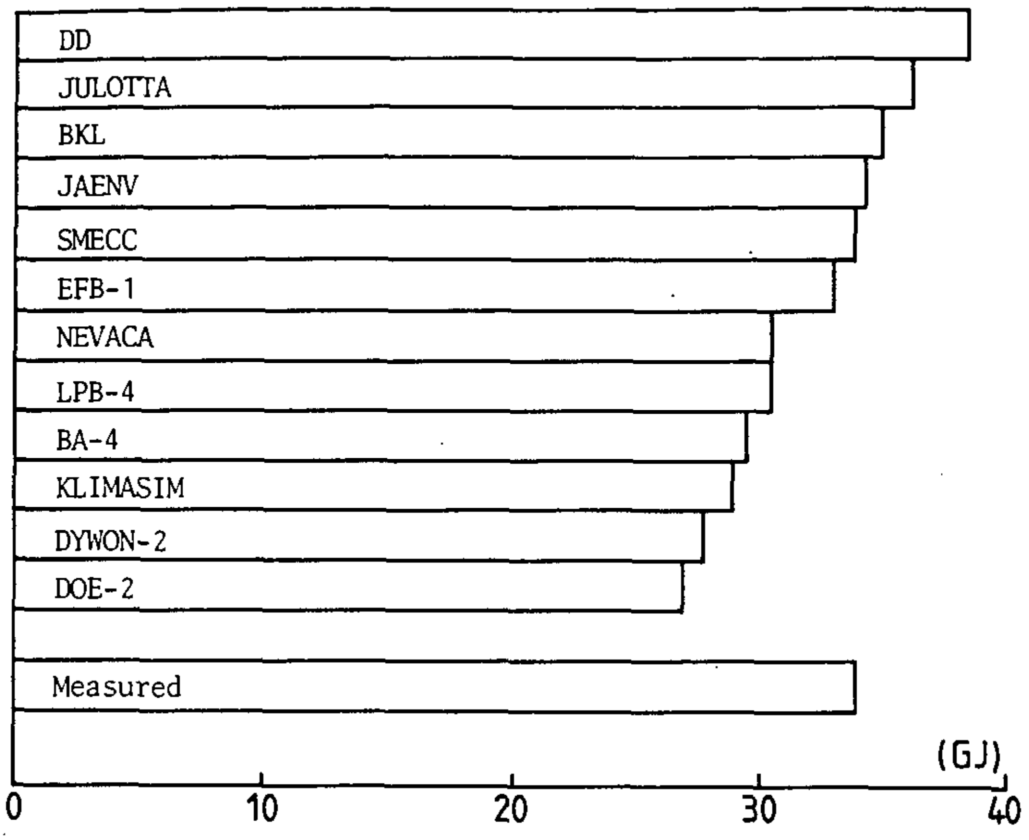


Figure 5.1 The Vetlanda house, original case. Five months' heat consumption.

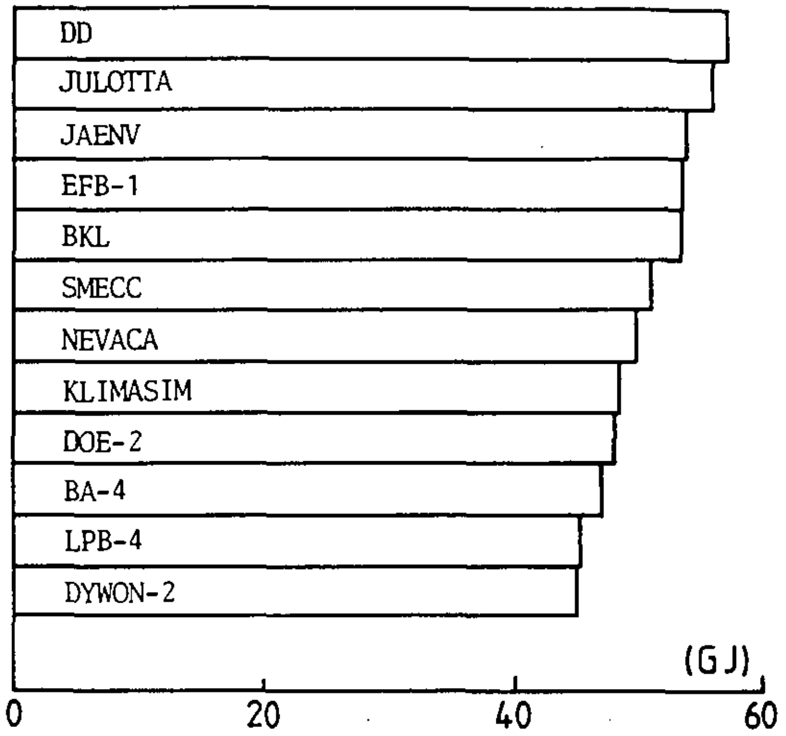


Figure 5.2 The Vetlanda house, case (b). Six months' heat consumption. (Decreased insulation).

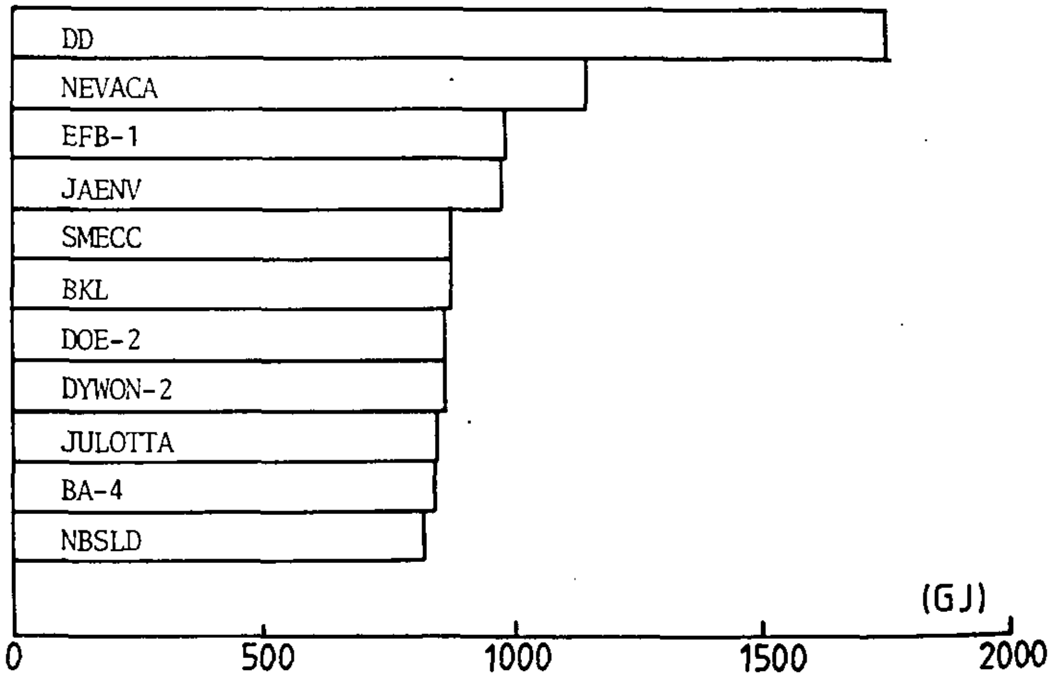


Figure 5.3 Estimated heating loads for the Teknikern building.

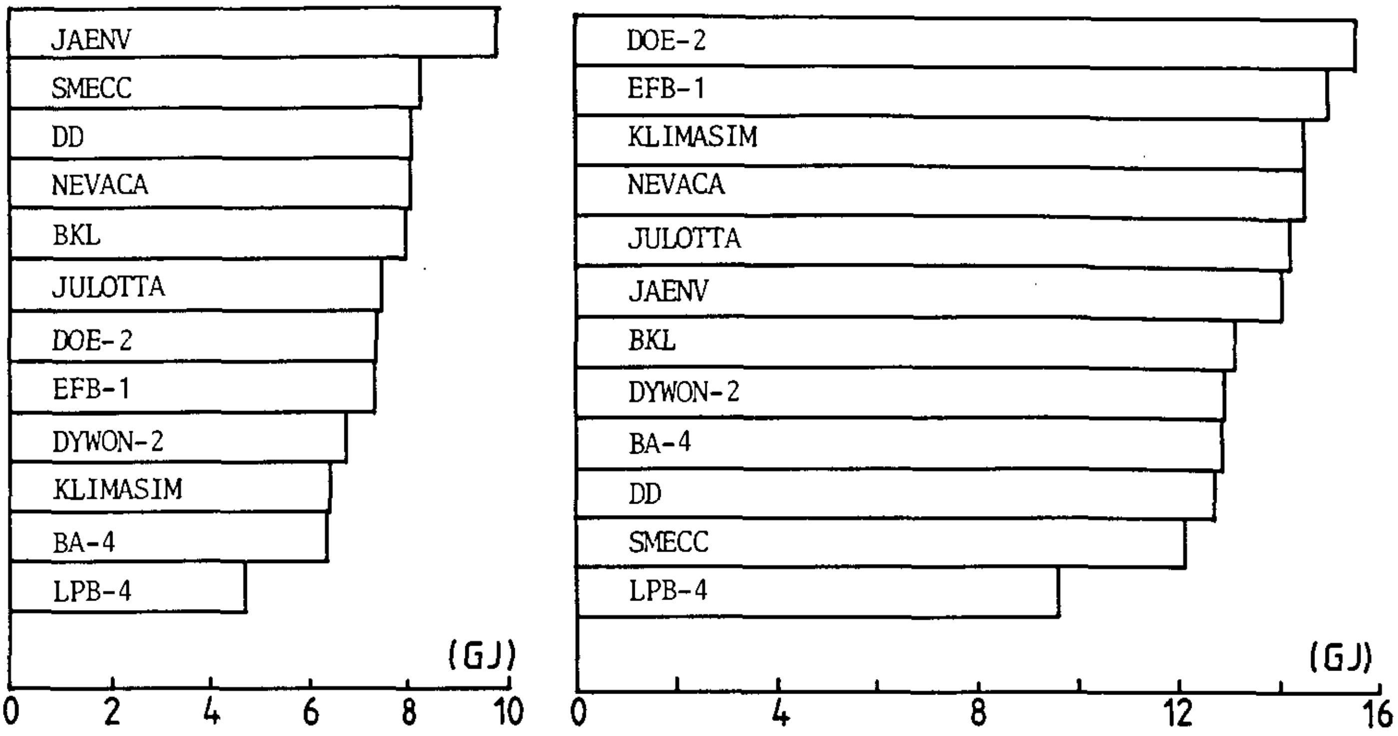
The yearly consumption estimated for the Teknikern building is shown in Figure 5.3. Most of the results are rather close to each other, but the degree-day method shows an unacceptable deviation from the other results. This is clearly caused by the fact that this method cannot take into account the relative high level of free heat in this example. Another observation is that the relation between the same methods changes when they are used for different types of buildings, e.g. the EFB-1 and the BKL-methods are rather close to each other for the Vetlanda house, case (b) (Figure 5.2), but differs about 13% for the Teknikern building. This again, requires more detailed examinations in order to find the reasons.

5.2 Predictions of energy conservation

The five parametric runs for the Vetlanda house form, together with the original case, five examples of predicted energy conservation. In these cases, all six months have been used as we no longer have any possibility of comparisons with the measurements.

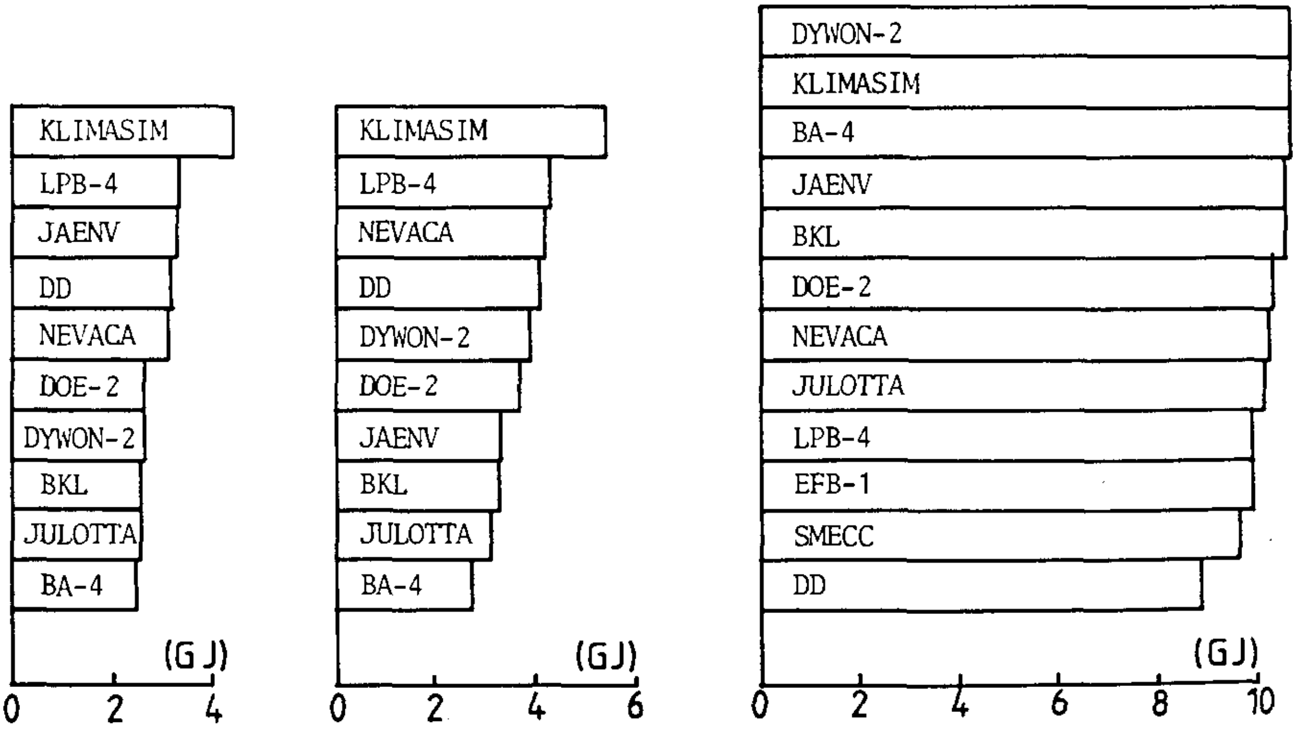
Figure 5.4 gives an overall picture of the estimated energy conservation. The following observations can be made:

> The change from four to two pane windows in case (a) influences two parameters, namely the transmission losses and the solar gain. The increased transmission losses will increase the load while the increased solar gain will decrease the load. Methods that over-estimate the solar gain might therefore under-estimate the change in energy requirement. The results in this case varied widely, the greatest estimated change is 2.1 times the lowest.
>
> In case (b), only the transmission losses are influenced and the results come slightly closer to each other than in case (a). Note also the rather large changes in the ordering of the results.



Case (a)
Double-glazing

Case (b)
Change of insulation



Case (c)
Night set-back

Case (d)
Set-back & carpet

Case (e)
Change in ventilation

Figure 5.4 The Vetlanda house. Estimates of energy conservation.

The night setback in case (c) again seems to give a wide range of results. The principle used in BA-4 makes this method less suited for calculations of such conservation methods as night temperature setback. This is indicated by the low value for BA-4 in case (c).

In case (d) the night setback is combined with a carpet which decreases the U-value of the floor. The variations in the results are less in case (d) than in case (c).

Only in the case (e) - change in the ventilation rate - most methods predict about the same energy conservation. This is, on the other hand, not surprising as the ventilation losses are well defined.

The order between the methods depends on what type of retrofit that is studied, e.g. DOE-2 predicts higher savings with change of insulation level than KLIMASIM, but in the case of night temperature setback the situation is the opposite. Note however, that the changing in the order overdramatizes the real changes in absolute or relative terms.

The deviations in the predicted savings arise the same questions as when looking at the energy consumption. In order to understand these deviations, the methods' way to calculate losses, internal and solar heat gain and its utilization, will be discussed in the following.

5.3 Calculation of ventilation losses

The energy consumption for the preheater in the Vetlanda house is a value reflecting the different methods' capability to predict ventilation losses. For the original case (Table 3.1) the greatest predicted consumption to the lowest is 1.04 to 1.00, reflecting only the fact that there is no standardized way to assume the yearly mean value of the heat capacity of the air. A similar picture is shown by Table 5.1, where the specific heat losses per degree are given for some of the methods.

Together with the earlier observations in section 5.2, all methods can be assumed reliable in the prediction of ventilation losses.

5.4 Calculation of transmission losses

For some of the methods, the specific heat losses through the floor and through all other surfaces are specified in Table 5.1. A difference of 1.0 W/^{o}C in specific transmission losses corresponds to about 0.6% changes in total losses and, with respect to the free heat in the building, to about 1% of the predicted energy consumption. With this as a background, the only noticeable deviations are the transmission losses through the other surfaces for the BA-4 and the EFB-1 methods. This might be a result of these methods' use of a combined air and surface temperature instead of a distinct room air temperature.

Some methods use a fixed ground temperature instead of the outdoor temperature when calculating the energy consumption. A change of this ground temperature by 1 ^{o}C will change the "degree-hours" for the floor (by 4344 in this example). For specific losses of 25 W/^{o}C this also causes a change of the same magnitude as the above discussed for errors in the specific losses.

The two above explanations for different transmission losses do not explain why the results for transmission through the floor seem to fall into three groups. There is no apparent reason for this.

Using only the total specific losses in Table 5.1, the EFB-1 method should give 12% higher energy consumption than the DYWON-2 method. According to Table 3.1, the difference is 20%

and the differences in calculated losses cannot explain the whole difference. Another example which requires an explanation is the difference between DOE-2 and JULOTTA, where the difference in total specific losses is about 1% and in energy consumption about 24%. This will be discussed further in following sections.

5.5 Calculation of internal load

The degree-day method is the only investigated method which does not take different internal loads into account. This can, in cases with high internal loads, give great errors. The heat consumption predicted by the degree-day method for the Teknikern building (Figure 5.3) illustrates this problem. For all the other methods, there exists no reason to expect any differences caused by different calculation of the amount of internal load. On the other hand, the utilization of the internal load may differ and this is discussed together with utilization of solar gain in section 5.7.

5.6 Calculation of solar gain through windows

This section will deal with solar gain through windows; the solar gain through opaque surfaces is here totally neglected.

As described in chapter 1, the problem of calculating solar gain through windows can be divided into three parts:

- calculating the radiation incident on vertical surfaces
- calculating the effect of shading
- calculating the transmission through the windows

These three steps have been examined for some of the investigated methods and some results are shown in Table 5.2 for the Vetlanda house and in Table 5.3 for the Teknikern building. The results from all six months for the Vetlanda house are also illustrated in Figure 5.5, to which the following discussion will refer.

In Figure 5.5 the results of the radiation on the south facade of the Vetlanda house without considering shading effects are shown. The values lie between 638 and 946 MJ/m^2 from the 6 months period. Two different circumstances can influence the results; namely, if the methods take the variation of the ground reflectivity into account and if the methods use average values in the calculations. These deviations in results are unacceptably large. One would think that there should be more uniformity, since this step of the calculation is based upon widely accepted principles of geometry.

Figure 5.6 shows the effect of shading according to Table 5.2. In case of BA-4, the ratio between columns 4 and 3 has been used as the shading ratio. The redcution factors vary from 0.39 to 0.83. Four of the seven results are grouped between 0.71 and 0.79 and according to qualitative considerations this band seems reasonable for the shading effects. Figure 5.7 represents the values of the transmission factor in the same manner. Values range between 0.48 and 0.63, which is too wide a band to be acceptable. Four of these values are found in the narrow band between 0.53 and 0.55, which seems to be an acceptable result for a four-pane window. To take the most frequently used values cannot be accepted as the proper method, but on the other hand, it seems to be reasonable from a qualitative point of view.

Finally, Figure 5.8 shows the solar gain inside the house and the values vary from 2.2 to 1.0, a totally unacceptable variation.

The greatest effect is that of shading. This is exemplified by the results from the SMECC method which gives the greatest radiation on the outside but, due to the great influence of shading, has the lowest solar gain inside the house. See Figure 5.8. Reasons for this large effect may be not only a simplified geo-

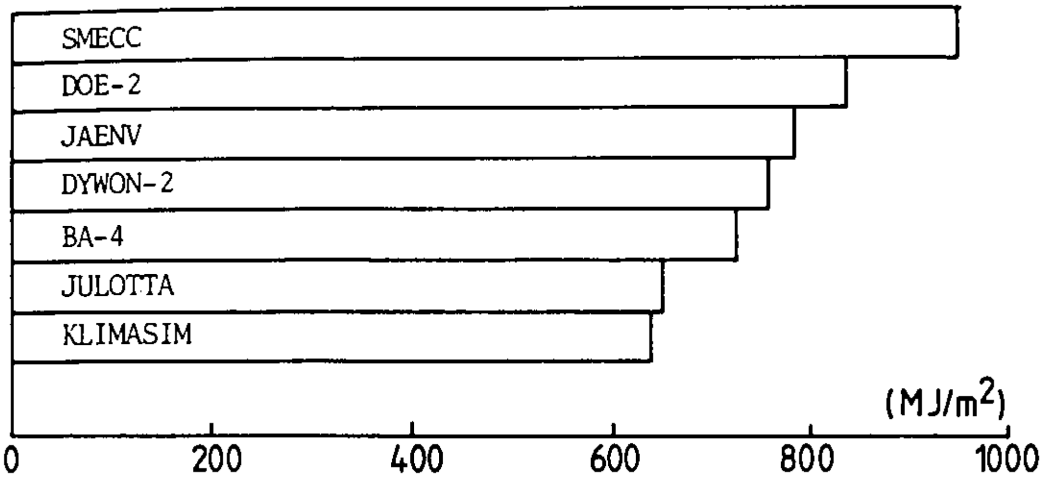


Figure 5.5 Solar radiation on unshaded south facade.

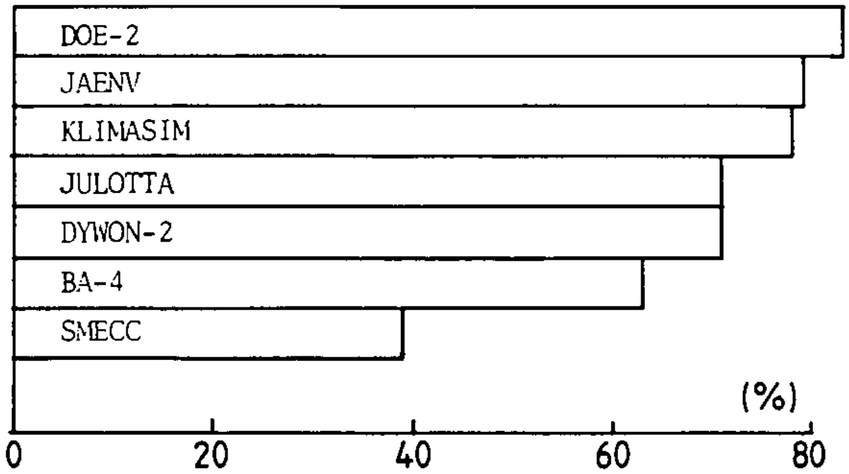


Figure 5.6 Influence of shading.

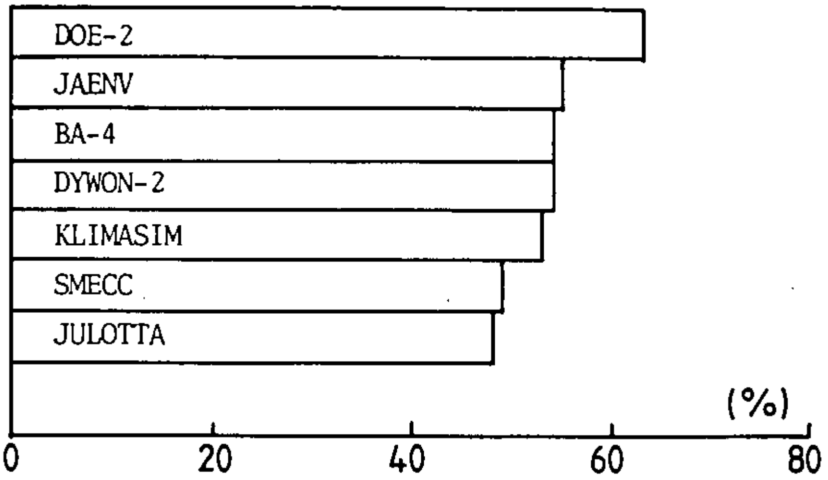


Figure 5.7 Influence of transmission.

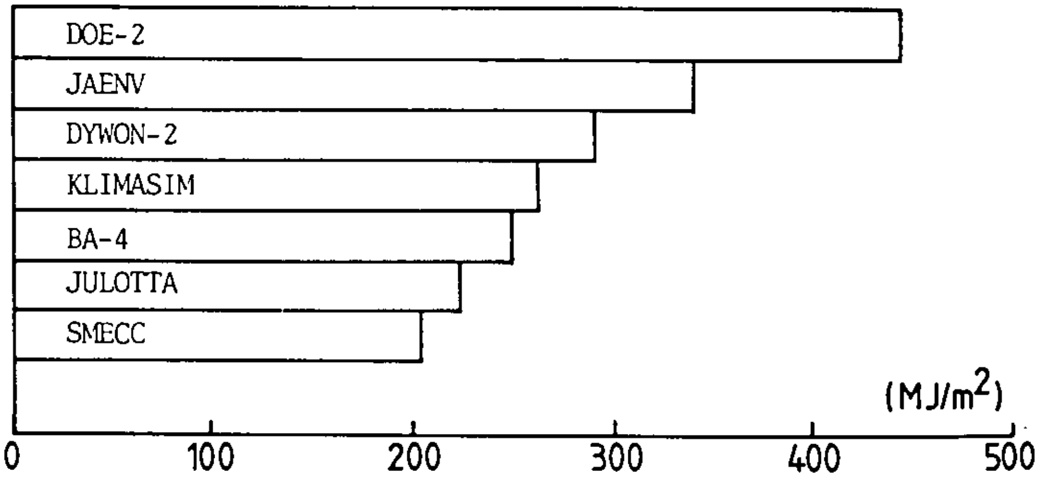


Figure 5.8 Solar gain through south windows.

metrical calculation, but also inadequate knowledge of the distribution of diffuse radiation. The wide variations in the effects of shading and transmission can, to some extent, be a result of how solar radiation on the south facade is split into direct and diffuse components.

5.7 Utilization of free heat

The calculation of the net heat consumption Q_{net} can always be represented by

$$Q_{net} = Q_{loss} - \eta \cdot Q_{gain}$$

where Q_{loss} is the sum of steady state heat losses exactly proportional to the time integral of the inside-outside temperature difference, and Q_{gain} the total available free heat in the building. The free heat can be utilized for heating only for an extent η, a factor partly representing the dynamic treatment of the building by the calculation method.

In Table 5.4, the steady state losses have been estimated according to the specific losses in Table 5.1 and the method's normal procedure of using sol-air temperature, etc. The total sum of free heat is the solar gain not included in the steady state losses and the internal loads. The net heat requirement is taken from Table 3.1 and the above equation is then used to calculate the utilization of the free heat.

Table 5.4 shows a wide variation in the utilization factor which can be explained partly by the different methods' mathematical models of the building.

5.8 Summary

In this chapter, deviations in the results of the investigated methods have been pointed out and possible causes for these deviations have been discussed.

Although a detailed description of the building envelope was given, the analysis ended up with a 15% variation in the loss calculation. A much bigger spread would be expected if each analyst was to extract the building data from drawings and other basic sources.

The different estimations of the solar gain cause a variation of 10% in the total energy consumption of the building, a spread which seems caused by different calculation algorithms rather than by the analysts' interpretation of data.

The utilization of free heat shows a variation of 40% which also results in another 10% variation in the total energy consumption. This variation is normally caused entirely by the mathematical model and cannot be influenced by the user.

Energy conservation effects are often smaller than the variation resulting from a use of different calculation methods. This underlines the fact that comparison of different conservation measures must be based on estimations using the same calculation method. The analyst must in each case make his own choice, but the analysis in this chapter may give some guidance.

Table 5.1 Specific Heat Losses (W/Deg C),
The Vetlanda House, Original Case.

	Vent. Losses	Transmission Losses Floor	All Other	Total Losses
LPB-4	-	27.5	83.0	-
BA-4	43.7	24.8	94.0	162.5
EFB-1	43.7	24.8	101.0	169.5
SMECC	44.3	27.4	87.5	159.2
DYWON-2	43.8	23.5	83.7	151.0
KLIMASIM	43.8	23.4	82.8	150.0
JULOTTA	43.9	23.6	84.5	152.0
JAENV	44.3	23.5	88.2	156.0
DOE-2	43.5	23.7	86.5	153.7

Table 5.2 Solar Radiation on South Facade, Vetlanda House (MJ/M**2,Month)

1: Unshaded on Outside
2: Shaded on Outside
3: Unshaded trough Window
4: Shaded trough Window
5: Shading = 2/1
6: Transmission = 3/1

December	1.	2.	3.	4.	5.	6.
BA-4	34	-	19	16	-	.56
SMECC	50	50	27	27	1.00	.54
DYWON-2	34	33	18	18	.97	.53
JAENV	37	37	20	20	1.00	.54
DOE-2	40	39	26	25	.97	.65
JULOTTA	27	26	14	13	.96	.52
KLIMASIM	27	27	14	14	1.00	.52

April	1.	2.	3.	4.	5.	6.
BA-4	193	-	103	42	-	.53
SMECC	245	15	134	8	.06	.55
DYWON-2	203	109	109	59	.54	.54
JAENV	201	112	110	62	.56	.55
DOE-2	250	186	153	115	.74	.61
JULOTTA	199	118	92	55	.59	.46
KLIMASIM	194	127	102	66	.65	.53

6 Month	1.	2.	3.	4.	5.	6.
BA-4	724	-	394	249	-	.54
SMECC	946	372	461	204	.39	.49
DYWON-2	756	539	406	290	.71	.54
JAENV	782	619	430	340	.79	.55
DOE-2	834	695	527	444	.83	.63
JULOTTA	649	463	312	224	.71	.48
KLIMASIM	638	498	335	261	.78	.53

Table 5.3 Solar Radiation on Southeast Facade, Teknikern (MJ/M**2,Month

1: Unshaded on Outside
2: Shaded on Outside
3: Unshaded trough Window
4: Shaded trough Window
5: Shading = 2/1
6: Transmission = 3/1

December	1.	2.	3.	4	5	6
BA-4	95	-	66	61	-	.69
SMECC	100	99	75	74	.99	.75
DYWON-2	100	94	74	69	.94	.74
JAENV	101	86	67	57	.85	.66
DOE-2	102	97	76	74	.95	.75

June	1.	2.	3.	4.	5.	6.
BA-4	471	-	310	105	-	.66
SMECC	431	4	323	3	.01	.75
DYWON-2	468	135	346	100	.29	.74
JAENV	441	234	291	154	.53	.66
DOE-2	494	269	353	193	.54	.71

Year	1.	2.	3.	4.	5.	6.
BA-4	3421	-	2320	1112	-	.68
SMECC	3343	941	2501	704	.28	.75
DYWON-2	3453	1591	2556	1177	.46	.74
JAENV	3350	2176	2211	1436	.65	.66
DOE-2	3666	2462	2683	1822	.67	.73

Table 5.4 Utilization of Free Heat in the Vetlanda House
(Original Case, Period December-April)

	Heat Losses	Solar Gain	Total Free Heat	Net Heat Requirement	Utilization of Free Heat
BA-4	43279	5653#	13968	29277	1.00
EFB-1	45142	5741#	14056	32892	0.87
SMEC	43124	7328*	15643	33706	0.60
DYWON-2	41555	7732*	16047	27553	0.87
KLIMASIM	39055	5084*	13399	28789	0.76
JAENV	45008	7780	16095	33997	0.68
DOE-2	43951	9139	17454	26849	0.98
MEAS.				33889	

Solar Gain through Window and outer Opaque Surfaces.
* Solar Gain through Window +10% for Outer Opaque Surfaces.

6 CONCLUSIONS AND RECOMMENDATIONS ON CALCULATION METHODS

After the analyses summarized in the previous chapter, the participants have agreed on the following conclusions and recommendations. It was also noted, that the analyses in this task confirm the conclusions and recommendations in the report "Comparison of Load Determination Methodologies for Building Energy Analysis Program, prepared for International Energy Agency, Energy Conservation in Building and Community Systems" by U.S. Department of Energy (DOE/CE/20184-1), 1981.

In one case, the annual heat consumption predicted by the different calculation methods has been compared with measured consumption. Even if some of the methods give a result close to that of the measurements, this might be a result of opposing eroors. Thus more detailed verifications of calculation methods have to be carried out.

The parametric runs on the Vetlanda house have shown the variety in the methods' response to different conservation measures. These measures have been chosen as rather normal conservation measures. In order to test the calculation methods, the variations could have been chosen with greater liberty in order to really probe the range of values resulting from the methods.

Calculation methods are of course important when planning field experiments. This is because the results from the experiment should be generalized. Thus the interaction between the calculation method and measured quantities has to be carefully observed. The data required by the calculation method as input have to be measured and the calculation method has to be able to handle the conservation measure in question.

The explicit purpose of this subtask was to find - if at all possible - one calculation method to recommend when predicting energy consumption and energy conservation in residential buildings. However, no such method can be clearly recognized, and we have instead discussed different qualities of the calculation methods and how well they fulfill these qualities. The conclusions regarding these qualities are based on:

- Results from the work inside this subtask
- Information from the authors of the methods
- The analysts' experiences with different calculation methods

The following table gives the cross-reference of chosen qualities, methods and conclusions. Carefully examined, the table could be useful when selecting a method for a certain purpose.

		Confidence in energy conservation by					The methods' treatment of								Other qualities		
Method	Classification according to section 2.1	Insulation level	Ventilation rate	No.of window panes	Night setback	Combinations	Transmission losses	Ventilation losses	Heat capacity	Solar shading	Solar transmission	Utilization of solar gain	Utilization of internal gain	Temperature control system	Common availability	Applicable for consultants	Applicable for research
LPB-4	Other correlation	H	H	M	L	M	S	C	-	C	S	S	C	S	G		
BA-4	Finite differences	H	H	H	M	H	C	C	C	C	C	C	C	S	G	M	G
EFB-1	Other correlation	H	H	H	M	M	C	C	S	S	S	S	S	-	G	G	-
SMECC	Other correlation	H	H	H	L	M	C	C	S	S	S	S	S	S	G	G	M
DYWON-2	Finite differences	H	H	H	H	H	C	C	C	C	C	C	C	C	-	M	G
KLIMASIM	Response factors	H	H	H	H	H	C	C	C	C	C	C	C	C	-	G	G
NEVACA	Corrected Degree-Day	H	H	M	L	L	C	C	-	-	S	-	-	-	M	G	-
DD	Degree-Day	H	H	M	L	L	S	S	-	-	-	-	-	-	G	G	-
BKL	Other correlation	H	H	H	M	M	C	C	-	S	S	S	S	S	G	G	-
JULOTTA	Finite differences	H	H	H	H	H	C	C	C	C	C	C	C	C	-	-	G
JAENV	Other correlation	H	H	H	M	M	C	C	S	S	S	S	S	-	-	G	-
DOE-2	Weighting factors	H	H	H	H	H	C	C	C	C	C	S	S	C	G	G	G
		H: High M: Medium L: Low					C: Complex S: Simplified -: Not at all								G: Good M: Medium -: No		

7 INFLUENCE OF INHABITANTS

7.1 Background

The energy consumption of residential buildings is normally influenced by the inhabitants. Thus the inhabitants and their behaviour must be taken into account when generalizing results from field experiments on retrofits of buildings. It is also known, that large spreads in energy consumption are shown even for identical houses. The influence of inhabitants may also have a specific national character which requires a knowledge in order to generalize from field experiments.

The original idea for this task, was to try to model the influence of inhabitants as a single parameter representing the difference between an unoccupied and an occupied building. This idea should allow to simply transform the results from experiments on retrofits between different countries. However, the question of inhabitants' behaviour is a complex one, and with existing experimental data only one attempt to establish such a factor has been carried out and is referred to in section 7.3.

The question of the influence of inhabitants has, as mentioned before, also been treated in subtask B of this annex (IEA Energy Conservation in Buildings and Community Systems, Guiding Principles concerning Design of Experiments, Instrumentation and Measuring Techniques, 1982).

7.2 Demands from the calculation methods

Every method used to predict the energy consumption in a building must take into account the management and use of the building, i.e.

Internal loads produced by:	occupancy cooking lighting

	hot tap water etc
Management of the heating and ventilating system:	boilers setpoints etc
Factors which change the heat losses:	mechanical ventilation airing shutters & blinds etc

In principle every method has to use schedules and/or formulas giving values and durations for all these parameters. The necessary details in these schedules and formulas depend on how detailed the model is used, for example an hour-by-hour calculation might (but not necessarily) need hourly data, whereas a method based on monthly periods might use monthly average values. The possible combinations between the groups depend partly on the building, e.g. without thermostats no setpoint adjustment can be performed.

The influence might also be divided into the following groups according to the manner which each factor can be treated in calculation methods:

Unconditional management measures

- heating operation
- built-in setpoints
- fixed mechanical ventilation
- time-controlled systems
- etc.

"Common patterns" or schedules

- occupancy
- cooking
- shutters
- etc.

"Conditional patterns" or formulas

- lighting
- setpoints
- airing
- etc.

The unconditional measures are easy to handle in a model, as they all are functions of time or outdoor conditions, etc. and do not depend on the inhabitants; they are built-in parts of the system. Such measures can be left outside our discussion of the inhabitant factor.

The "common patterns" include the use of a building caused by traditions in the cultural area in question, e.g. it seems to be a reasonable assumption that occupancy and cooking in each area or country follow some common pattern. This might also be valid for the use of shutters during the night, and some types of airing, etc. Also social factors, family size, etc. might influence these patterns. Common patterns may be given as time schedules.

The "conditional patterns" include the behaviour of the inhabitants related to the indoor climate. For example, a high indoor temperature can result in the opening of windows and turning down the thermostat. Another example is the use of lighting and blinds which depends on the amount of daylight and the solar insolation reaching into the building. Conditional patterns may be given as functions of indoor climate, outdoor climate, thermal comfort, etc.

The above discussed patterns may also change in time (changes in family size, etc.) or by retrofits of the building. One example of the latter type of change is when extra insulation is used to obtain higher comfort from increased indoor temperature instead of saving energy by maintaining the lower indoor temperature.

7.3 A Swiss investigation

Looking for a single family building to monitor and to obtain data for validation of simulation programs, EMPA chose a prefabricated type, which has been built 100 times in a more or less identical version. At the same time the discussion about user influence came up. They decided as a result to enlarge this experiment of measuring an empty house by a survey of as many of these house owners as possible. With the advantage of knowing very well the behaviour of the empty house, they expected more quantitative information about the user influence itself. They obtained the agreement of about 60 house owners to cooperate in this investigation.

The occupant influence on heating energy consumption is here defined as the difference between the energy consumption for heating of an unoccupied house kept at 20 °C during the day and setback 2 °C at night, and the energy consumption for heating of the same house with occupants.

The experimental investigations with the unoccupied house have been used to check and adjust the program JAENV, which was then used to calculate the theoretical energy consumption of each of the other 60 houses individually under unoccupied conditions. The difference between the measured effective value and the calculated value was then established as user influence. The total sample of occupant influences was divided into classes regarding different parameters. The distributions within the classes were then analyzed, whether their mean values are separated significalntly (i.e. the parameter under consideration has some influence) or not.

One of the major results of this investigation is the finding that the mean value of the occupant influence is practically zero, but with a spread of ±50% of the consumption of the unoccupied house as defined above. According to these experiments the conclusion is that in simplified calculation methods no inhabitant term has to be introduced, but one has to be aware of the spread the occupants may cause.

This interpretation has some limits. The special kind of relatively cheap single family houses under consideration preselected a certain class of people to buy them. These may not be representative of the Swiss population in general. Moreover it is to be expected that the occupant influence associated with people living in rented apartments, or in other social or climatic circumstances, could be much different.

For some parameters a correlation with a narrow margin above the confidence level was found; for some others the correlation was lost in the errors. From these results we can learn that in order for an investigation of this kind to bring more significant results, the sample has to be enlarged by about a factor of 10. Knowing the spread of the occupant behaviour one can evaluate the necessary size of the sample in case one wishes to investigate the interaction between the occupants and different types of retrofits.

Ref.: EMPA report 41643.

7.4 Conclusions and recommendations

After discussions of the material in this chapter, the participants in this annex reached some conclusions of how the influence of inhabitants can be treated.

First, all participants agreed on the fact that this is a complex problem and a complete investigation could not be included in this annex. Nevertheless, it is a very important field and further investigations ought to be carried out.

Second, the approach to describe the influence of inhabitants as common patterns and conditional patterns is very useful when one needs to generalize results from field experiments on energy-saving measures. These patterns are clearly indicated as statistical data and have to be treated as such. It is therefore of great importance in a field experiment that either the detailed patterns are monitored, or that the experiment is designed so that "representative patterns" can be assumed. If this is done, a calculation method ca be used with climatic data and "representative patterns" for another location, thus allowing the results to be generalized to other places and countries. How detailed these patterns need to be partially depends upon the calculation method used.

Third, with the limited number of available experiments, it has not been possible to evaluate the original idea of treating the inhabitant factor as a constant. The Swiss investigation shows however, that further experiments in this direction ought to be carried out.

APPENDIX A

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APPENDIX B
BUILDING SPECIFICATIONS

1 SPECIFICATION OF THE VETLANDA HOUSE

1.1 Location, orientation and surroundings

The house is situated in the town of Vetlanda with

Latitude	57.42 degrees North
Longitude	15.08 degrees East
	(Degrees and decimals of degree)

The longitude of the standard time meridian is 15.00 degrees east (Swedish Standard Time).

The house is to some extent shaded from the sun by the surroundings and some neighbouring buildings, but as the solar and sky radiation are measured at the site this shielding can be neglected and the house can be assumed to be placed with a free horizon.

This may introduce some small error, especially at low solar altitudes during the afternoons, but to overcome this one has to transform the measured solar radiation to radiation with a free horizon. This transformation will introduce new errors and therefore the measures values are used as they are.

The ground is assumed to have a diffuse reflectivity to all solar radiation of 0.2 without snow and 0.8 with snow. The periods with snow are given in the weather tape specification.

The north facade is facing 15.00 degrees west of north as shown in Figure 1.1.

1.2 Dimensions

Figures 1.2 - 1.6 show the plan, a section, elevations and window and door details of the house. These figures provide all dimensions of the building. Note that the scales might be erroneous, so no dimensions should be measured from the figures.

The details of the house are somewhat simplified to avoid misunderstandings, but care in any case should be taken to include all parts that influence the energy consumption of the building.

1.3 Thermal properties

1.3.1 Fabrics

The thermal properties of the materials are given in Table 1.1. In case of composite layers, e.g. insulation between studs, weighted properties are used.

1.3.2 Outer opaque surfaces

The emissivity for long wave radiation is 0.93.

The absorptivity for solar radiation of all outer opaque surfaces is 0.80.

If more detailed calculation is not carried out, following film coefficients must be used:

Convective	11.7	$W/m^2,K$
Radiative	4.3	$W/m^2,K$

1.3.3 Inner opaque surfaces

The emissivity for long wave radiation is 0.93

No inner surfaces in the attic is exposed to solar radiation. For the rooms' surfaces, the absorptivities for solar radiation are:

Ceilings	0.20
Floors	0.70
Inside external doors	0.80
Other internal surfaces	0.50

If more detailed calculation is not carried out, following film coefficients are to be used:

Convective at bottom floor	2.0 $W/m^2,K$
Convective at other surfaces	3.0 $W/m^2,K$
Radiative	5.3 $W/m^2,K$

1.3.4 Windows

All windows are sealed units with 4 mm clear glass with 12 mm air gaps between them. The south facing windows are quadruple glazed, all others triple glazed, except for door units, which are double glazed.

The characteristics for solar radiation of normal incidence on a single sheet of glass are:

Transmitted	0.85
Reflected	0.07
Absorbed	0.08

The heat resistance and capacity of the glass are neglected.

The emissivity for long wave radiation is 0.93 for all glass surfaces.

If more detailed calculation of heat transfer through windows is not carried out, the following film coefficients and resistances must be used:

Outside convective	11.7	$W/m^2,K$
Outside radiative	4.3	$W/m^2,K$
Inside convective	3.0	$W/m^2,K$
Inside radiative	5.3	$W/m^2,K$

The thermal resistance of each air gap 0.17 $m^2,K/W$.

1.4 Infiltration and ventilation

Infiltration and ventilation flows are given in Table 1.2 with the flows referred to a 20 °C air temperature.

The infiltration flows are assumed as independent of the ventilation system.

Forced ventilation is used between 12.00-13.00 each day, otherwise normal ventilation is used.

The inlet air is preheated to 16 °C whenever the outdoor air is below this level, otherwise the inlet air has outdoor air temperature and the preheater is completely cut off.

The air flows between rooms passes the internal doors and should be calculated only from the ventilation flows without regard to the infiltration. No flow is assumed between room 1 and 3. The fan powers are totally excluded from the calculation.

1.5 Heating system

The heating system consists of the preheater in the ventilation system and direct electrical radiators in each room, except for room 10, which has no heating system. In the calculations we assume "perfect" systems in each room - i.e.

Each room-thermostat has a setpoint of 20 °C and the system provides each room with the exact amount of heat needed to maintain the air temperature in that room. If the indoor air temperature in a room exceeds 20 °C, all heat to that room is cut off.

1.6 Domestic hot water

No domestic hot water is used.

1.7 Internal loads

All internal loads are assumed as convective heat to the room air. The loads and schedules are for all days:

Room 1	800 W	between	12.00-13.00,	otherwise	300 W
Room 6	100 W	"	07.00-08.00,	"	zero
Room 7	200 W	"	07.00-08.00,	"	zero
Room 8	100 W	"	07.00-08.00,	"	zero
Room 9	875 W	"	20.00-21.00,	"	275 W

1.8 Specifications for the parametric studies

These studies include fice cases, each case specified by the original specification of the Vetlanda house and the changes given in the list below. Note that the only changes in a specific case are those given in the list, e.g. case (c) has the original type of windows, wall insulation etc., and the only change from the original specification is the setpoint schedule.

Case (a)

All windows are double glazed units with 4 mm clear glass with 12 mm air gaps.

Case (b)

External walls (not south):
Insulation layer changed from 190 mm to 50 mm.

Inner roof:
Fiber glass of 130 mm is excluded
Insulation layer changed from 170 mm to 100 mm.

Case (c)

The setpoints in all rooms are 16 °C between 22.00-06.00 during all days of the week, and 20 °C the remaining hours. (No change for the preheater's setpoint!).

Case (d)

Floor slab:
The thermal resistance of the carpet changed from 0.08 to 1.00 m^2,K/W.

Setpoints:
As in case (c).

Case (e)

Double all normal ventilation and exclude the forced ventilation. Use infiltration as in the original specification. Thus we have for 24 hours/day:

Room	Infiltration	Ventilation (m^3/h) Inlet	 Exhaust
1	3.0		120.0
2	0.3		40.0
3	1.2		
4	1.3		40.0
5	1.0		
6	1.9	40.0	
7	3.0	40.0	
8	3.0	40.0	
9	9.4	80.0	
10			
Total	24.1	200.0	200.0
Attic	265.0		

1.9 Simplifications

Some of the investigated calculation methods can not handle many details. For these methods the following simplifications were recommended by the analysts.

Number of rooms

As a first step the house can be assumed to have five rooms as follows:

a) Room 2,3,4,5 and 10 are treated as one room
b) Room 7 and 8 are treated as one room
c) All partition walls inside these new rooms are neglected

As a second step the whole house can be treated as one room without any partition walls at all.

All room numbers are according to Figures 1.1 and 1.3.

The attic

In order to simplify the treatment of the attic, its ventilation, the outer roof and the outside film coefficient can be modeled with a thermal resistance of 0.30 m^2,K/W between the top of the inner roof and the outdoor air. The given value can be discussed, but to avoid problems all participants were recommended to use either this value or the original specifications.

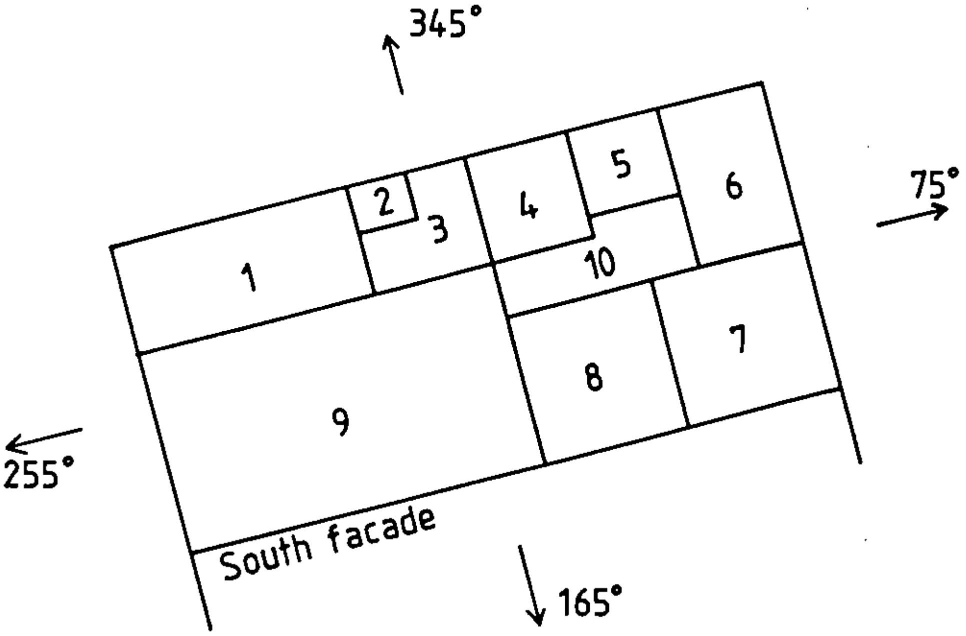


Figure 1.1 Orientation and room numbers.

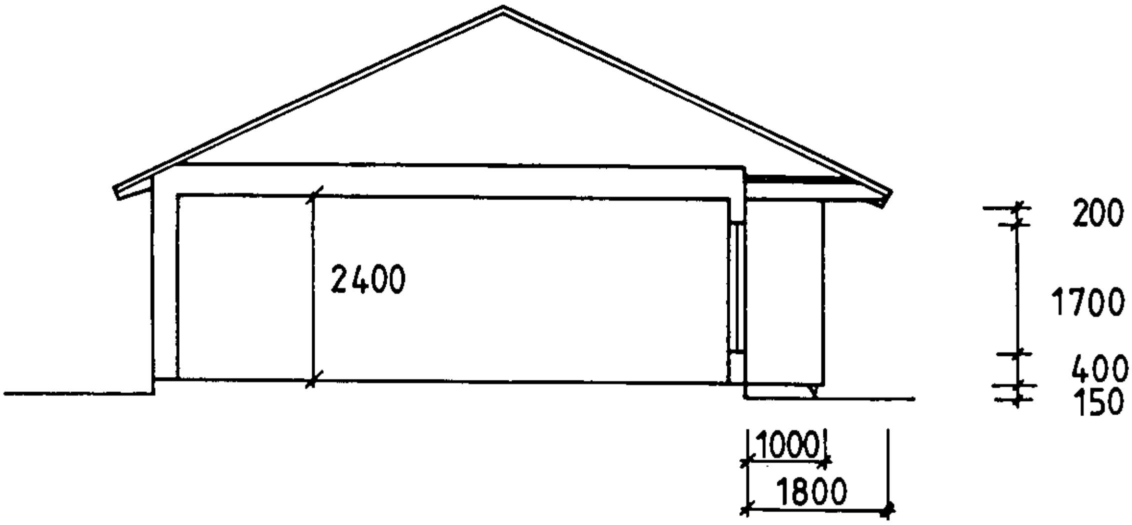


Figure 1.2 Section of the Vetlanda house.

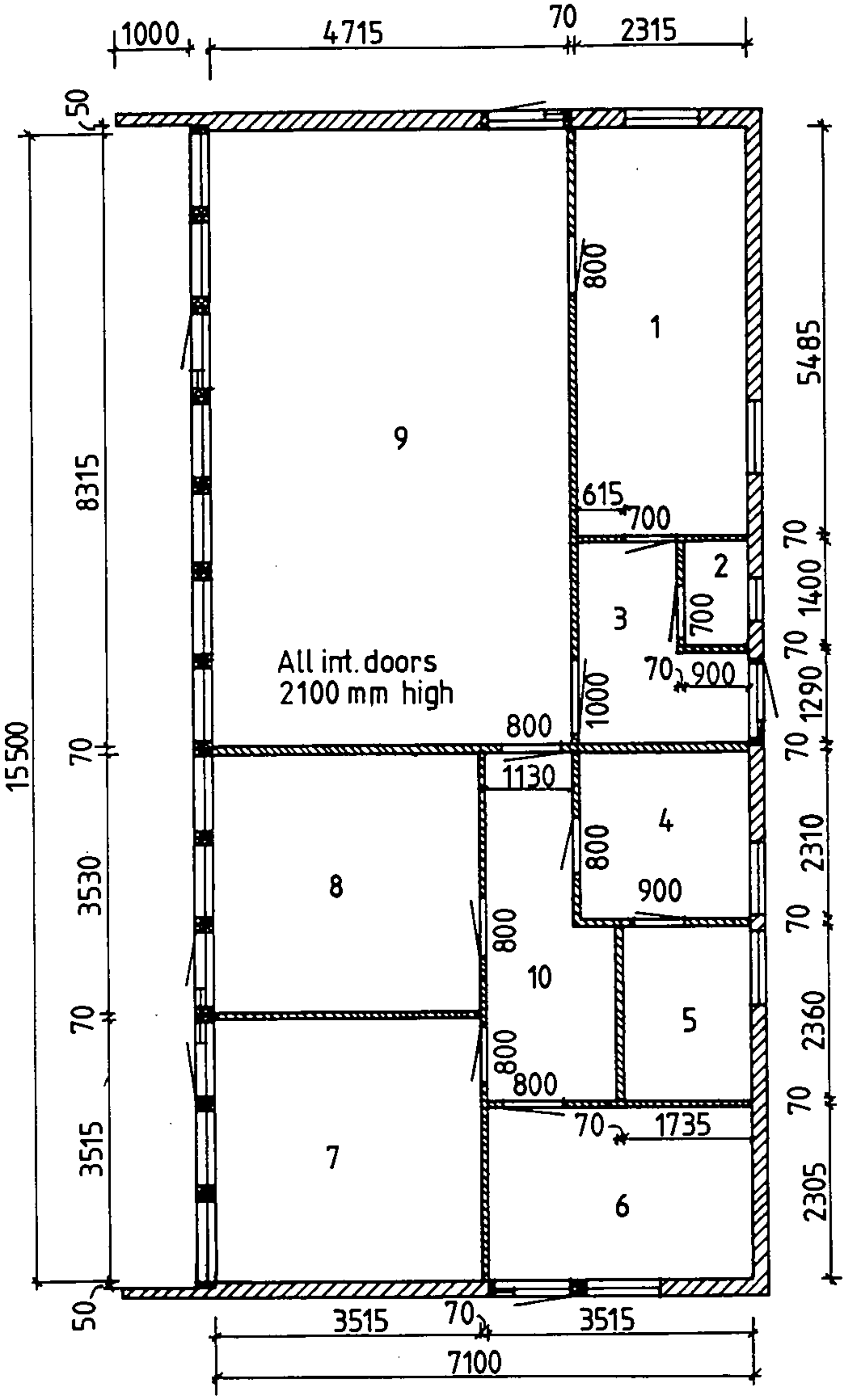


Figure 1.3 Plan and inner dimensions of the Vetlanda house.

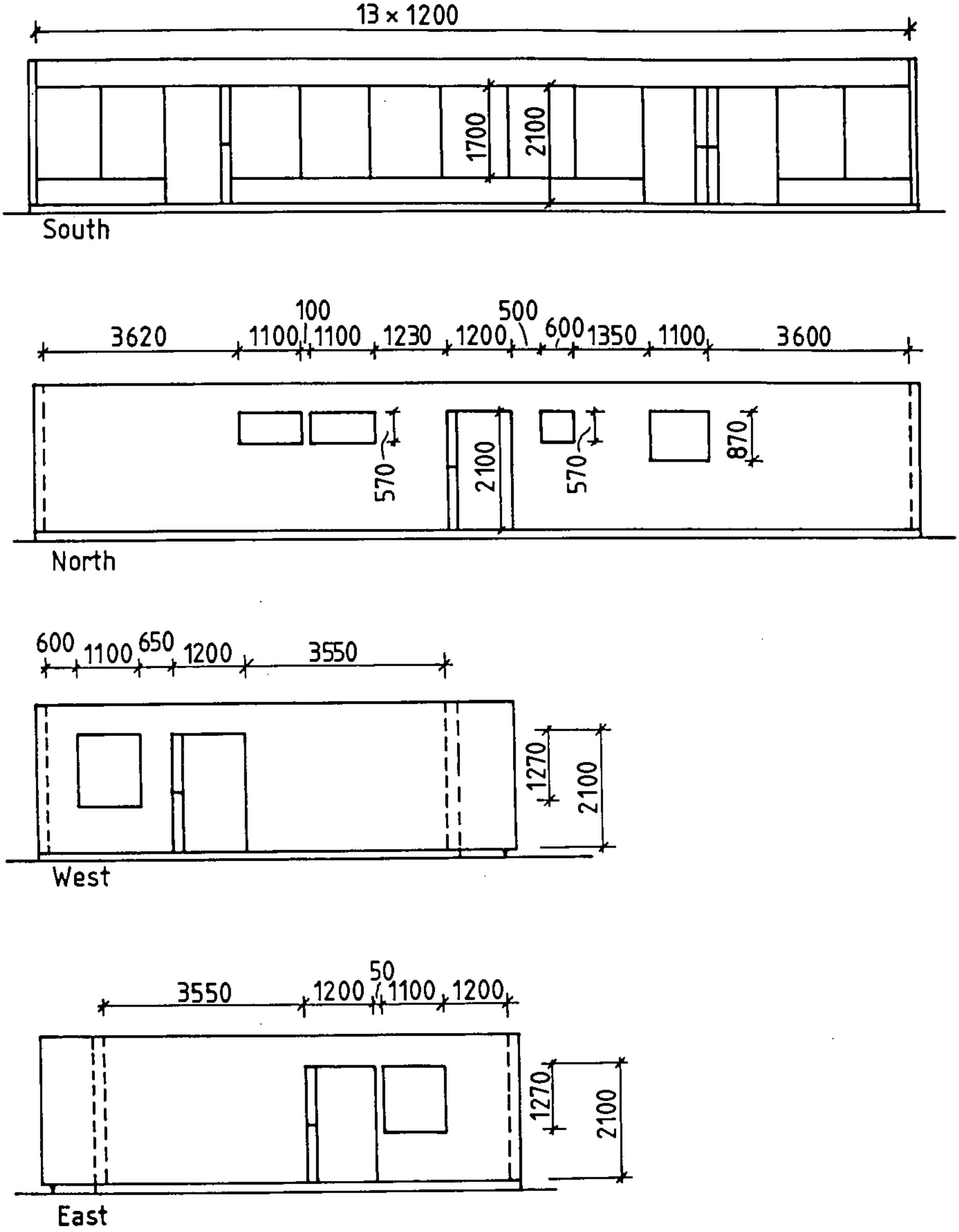
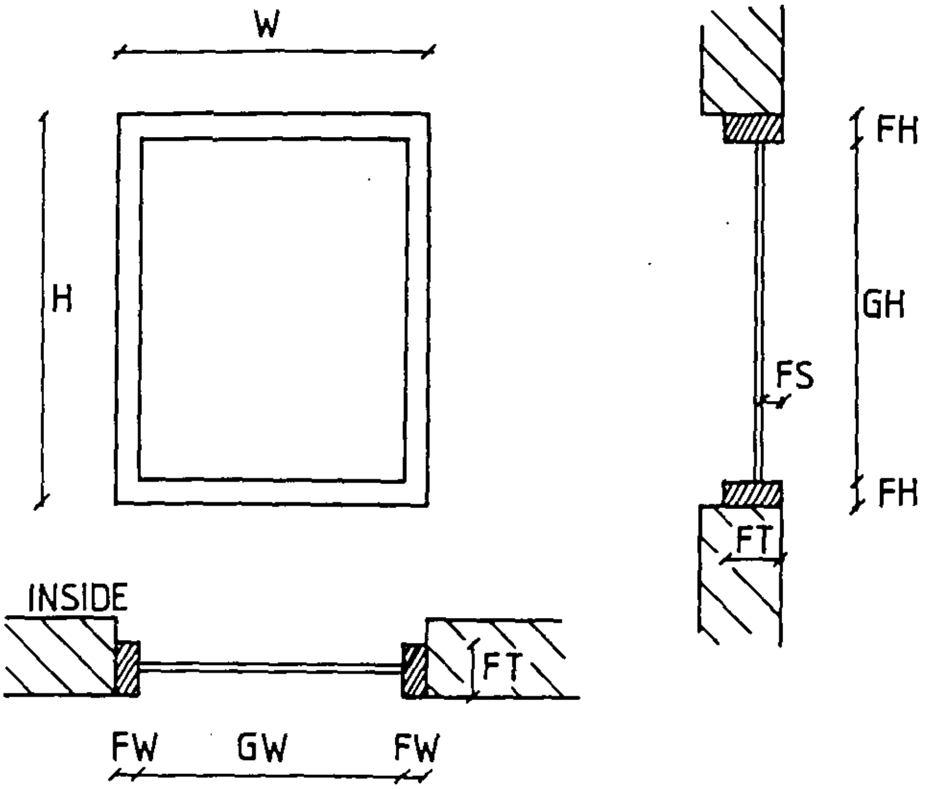


Figure 1.4 Facades of the Vetlanda house.



	Total size		Glass size		Framework			
	W	H	GW	GH	FT	FW	FH	FS
South	1200	1700	1090	1630	180	55	35	20
North	1100	570	910	380	100	95	95	20
North	600	570	410	380	100	95	95	20
North	1100	870	910	680	100	95	95	20
East-West	1100	1270	910	1080	100	95	95	20

Figure 1.5 Window dimensions of the Vetlanda house.

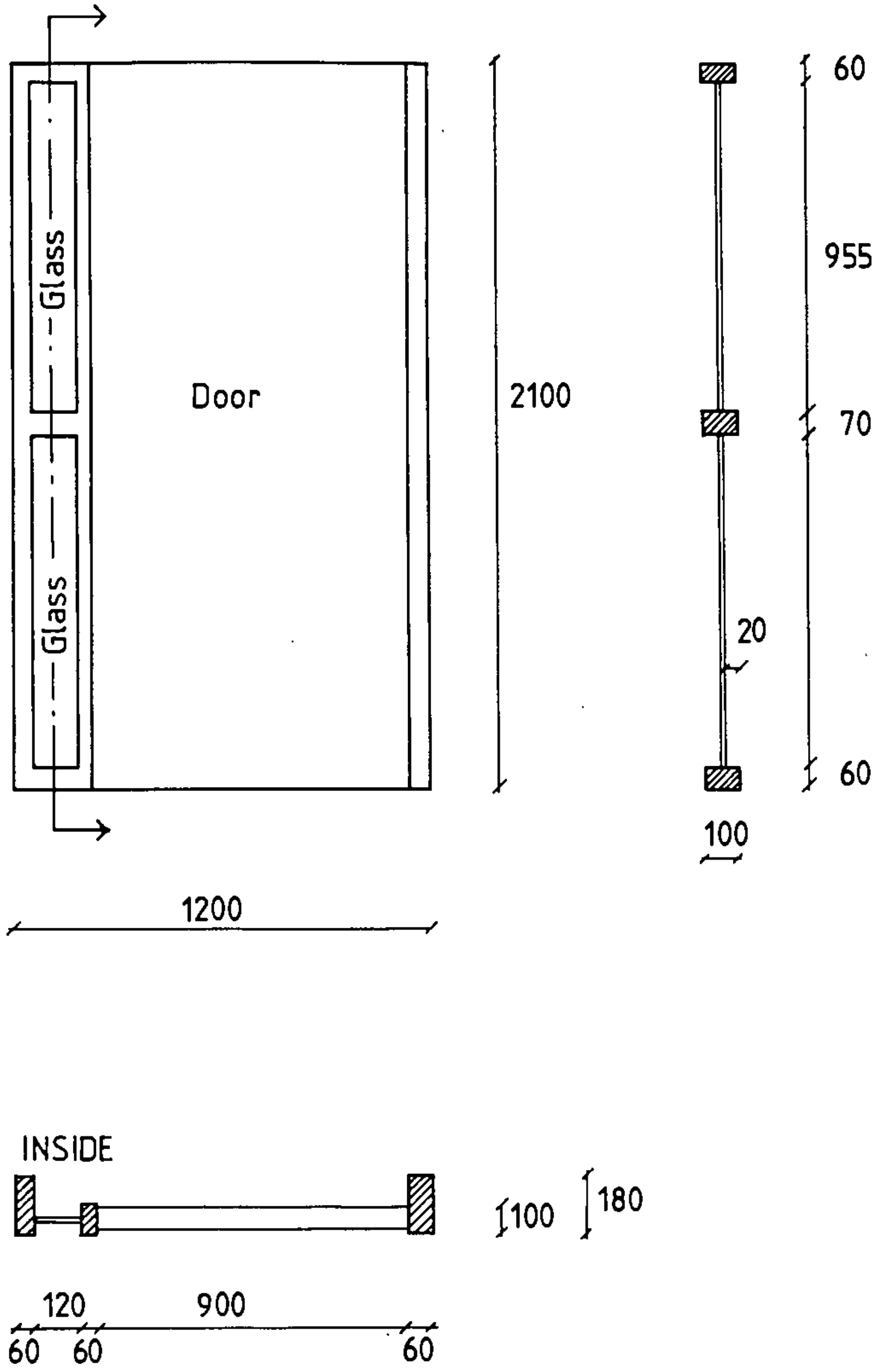


Figure 1.6 External doors' dimensions of the Vetlanda house.

Table 1.1 Thermal properties of building fabric

	Thickness mm	Conductivity W/m,K	Density kg/m^3	Specific heat J/kg,K	Thermal resistance $m^2,K/W$
INTERNAL WALL					
Gypsum	13	0.46	900	1090	
Cavity	45	-	-	-	0.05
Gypsum	13	0.46	900	1090	
INTERNAL DOOR					
Wood	25	0.14	500	2720	
EXTERNAL WALL (SOUTH)					
Inside					
Board	13	0.14	600	1340	
Insul.layer	95	0.070	150	880	
Asph.board	12	0.050	340	1340	
Cavity	20	-	-	-	0.05
Wood panel	40	0.14	500	2720	
Outside					
EXTERNAL WALL (NOT SOUTH)					
Inside					
Gypsum	13	0.46	900	1090	
Insul.layer	190	0.055	150	880	
Asph.board	12	0.050	340	1340	
Cavity	20	-	-	-	0.05
Wood panel	40	0.14	500	2720	
Outside					
EXTERNAL DOOR					
Wood panel	20	0.14	340	1300	
Insulation	50	0.050	100	600	
Wood panel	20	0.14	340	1300	

Table 1.1 Thermal properties (cont'd)

	Thickness mm	Conductivity W/m,K	Density kg/m^3	Specific heat J/kg,K	Thermal resistance $m^2,K/W$
INNER ROOF					
Top					
Fiber glass	130	0.040	24	750	
Insul.layer	170	0.049	64	910	
Cavity	28	-	-	-	0.18
Gypsum	9	0.46	900	1090	
Bottom					
OUTER ROOF					
Top					
Roof bricks	20	1.74	2000	880	
Cavity	20	-	-	-	0.05
Wood panel	20	0.14	500	2720	
Bottom					
FLOOR SLAB					
Carpet	-	-	-	-	0.08
Concrete	160	1.74	2300	880	
Insulation	120	0.040	150	750	
Ground	-	1.15	1400	1670	
FRAMEWORK					
Wood	See figures	0.14	500	2720	
ATTIC WALLS*					
Wood	20	0.14	500	2720	

* and the attic floor extending beyond the south facade.

Table 1.2 Infiltration and ventilation in the Vetlanda house

Room	Infiltration	Ventilation (m^3/h)			
		Normal		Forced	
	(m^3/h)	Inlet	Exhaust	Inlet	Exhaust
1	3.0		60.0		210.0
2	0.3		20.0		20.0
3	1.2				
4	1.3		20.0		20.0
5	1.0				
6	1.9	20.0		20.0	
7	3.0	20.0		20.0	
8	3.0	20.0		20.0	
9	9.4	40.0		190.0	
10					
TOTAL	24.1	100.0	100.0	250.0	250.0
Attic	265.0				

Note: for forced ventilation given values should be used, not sum of normal and forced.

2 SPECIFICATION OF THE TEKNIKERN BUILDING

2.1 Location, orientation and surroundings

The building is situated in Stockholm with

Latitude	59.33 degrees North
Longitude	18.03 degrees East
	(Degrees and decimals of degrees)

The longitude of the standard time meridian is 15.00 degrees east (Swedish Standard Time).

The building is assumed to be placed with a free horizon and no solar shading from neighbouring buildings.

The ground has a diffuse reflectivity to all solar radiation of 0.20 during the whole year.

The N/E facade of the building is orientated exactly to the north-east.

2.2 Dimensions

Figures 2.1 - 2.3 show plans, sections and elevations of the building. All dimensions are provided on these figures. Note that the scales might be erroneous and therefore, no dimensions should be measured from the figures.

The buildings is to a great extent simplified to avoid misunderstanding and to reduce the calculation work, but it is acceptable in this form since it is useful when studying the capability of different methods to handle big buildings.

Internal doors are assumed to have the same thermal parameters as the walls in which they are placed.

All frameworks are neglected, thus the dimensions on Figure 2.3

give glass and external doors' areas.

2.3 Thermal properties

2.3.1 Fabrics

The thermal properties are given in Table 2.1.

2.3.2 Outer opaque surfaces

The emissivity for long wave radiation is 0.93.

The absorptivities for solar radiation are:

Roof	0.80
Walls	0.50

Constant values used for film coefficients are:

Convective	11.7 W/m^2,K
Radiative	4.3 W/m^2,K

2.3.3 Inner opaque surfaces

Emissivity for long wave radiation: 0.93.

Absorptivities for solar radiation:

Ceilings	0.20
Floors	0.70
Other	0.50

If constant values are used, the film coefficients are:

Convective	3.0 W/m^2,K
Radiative	5.3 W/m^2,K

2.3.4 Windows

All windows have 2 panes of 3 mm clear glass with 20 mm air gaps between them.

The characteristics for solar radiation of normal incidence on a <u>single</u> sheet of glass are:

Transmitted	0.86
Reflected	0.07
Absorbed	0.07

The heat resistance and capacity of the glass are neglected.

The emissivity for long wave radiation is 0.93 for all glass surfaces.

If more detailed calculation of heat transfer through windows is not carried out, the following film coefficients and resistances have to be used:

Outside convective	11.7 $W/m^2,K$
Outside radiative	4.3 $W/m^2,K$
Inside convective	3.0 $W/m^2,K$
Inside radiative	5.3 $W/m^2,K$

Heat resistance of each air gap 0.17 $m^2,K/W$.

2.4 Infiltration and ventilation

Infiltration and ventilation flows are given in Table 2.2 with the flows referred to a 20 °C air temperature.

The infiltration is assumed to be the same during the whole year and independent of the ventilation flows.

The ventilation system is an exhaust air system.

2.5 Heating system

In each room in the basement we assume a "perfect" heating system - i.e.

> Each room thermostat has a setpoint of 20 °C and the system provides each room with the exact amount of heat needed to maintain the air temperature in that room. If the indoor air temperature in a room exceeds 20 °C, all heat to that room is cut off.

2.6 Domestic hot water

No domestic hot water is used.

2.7 Internal loads

The basement and the attic have no internal loads. Each room has the internal load given in Table 2.3. These loads are treated as convective loads to the room air and will be the same all days of the year.

2.8 Treatment of the basement

To avoid the problems associated with calculating the heat transfer with the ground, the basement has been excluded and the bottom surface of the slab between basement and first floor is kept at 20 °C. This simplification is included in the results in this report.

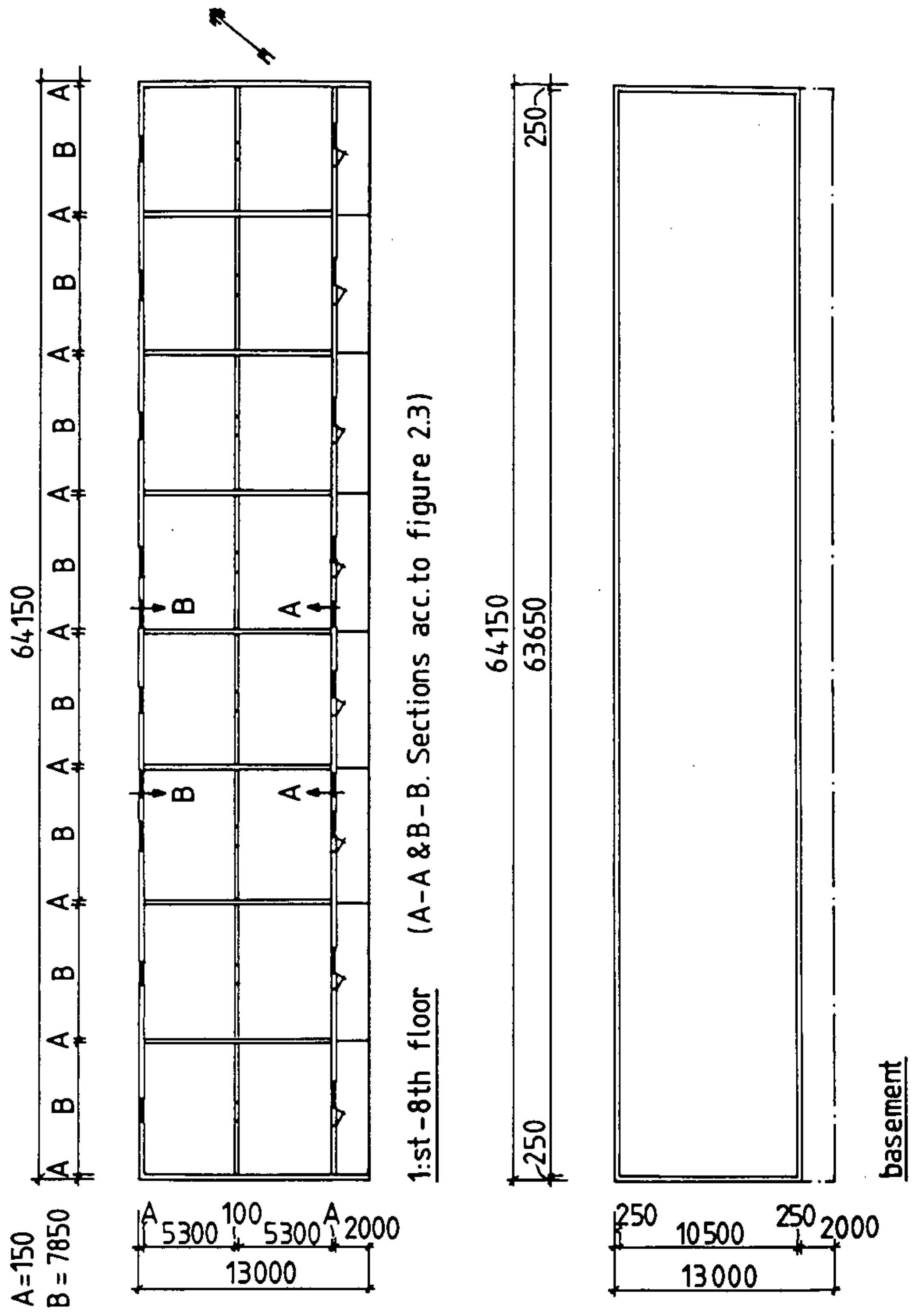


Figure 2.1 Plans of the Teknikern building.

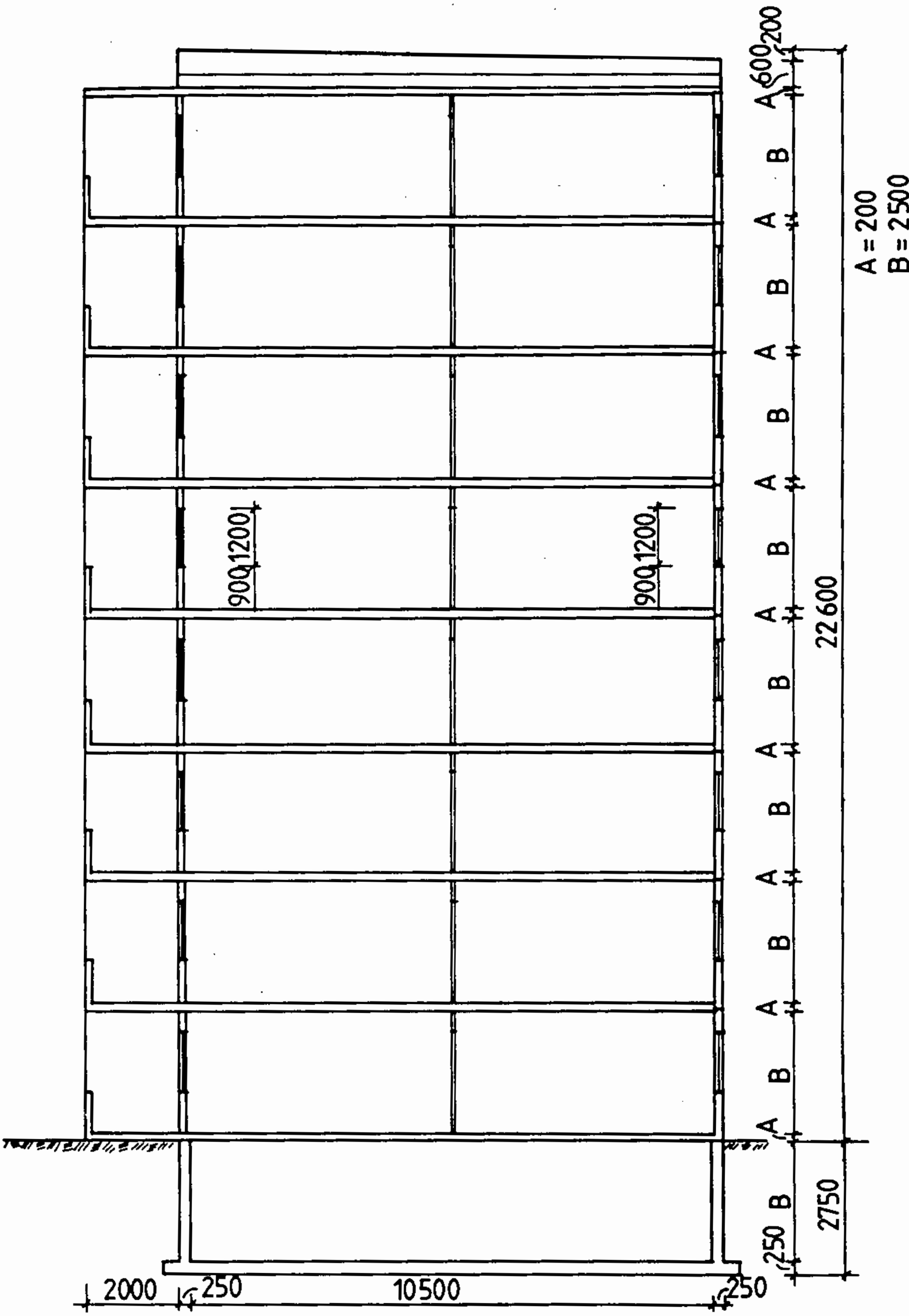
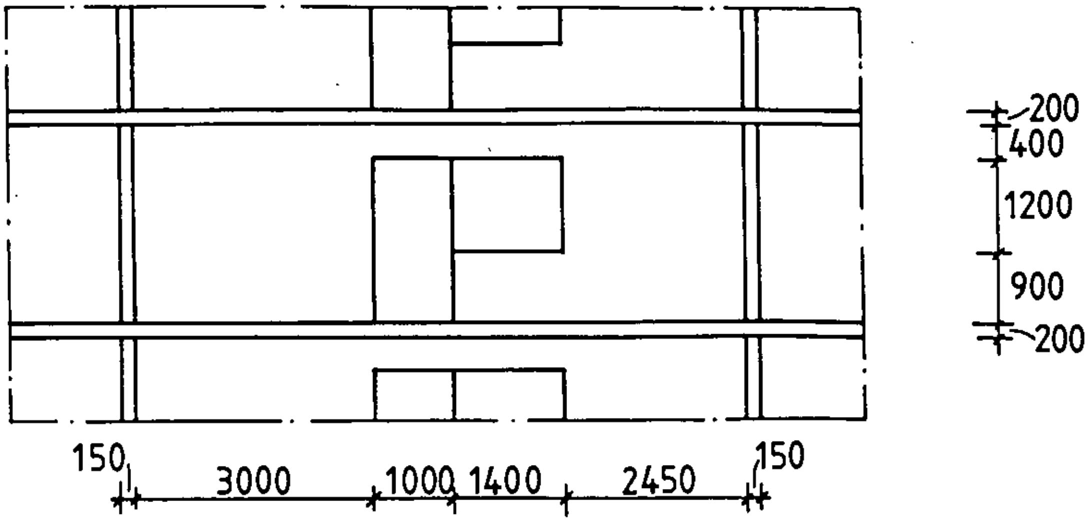
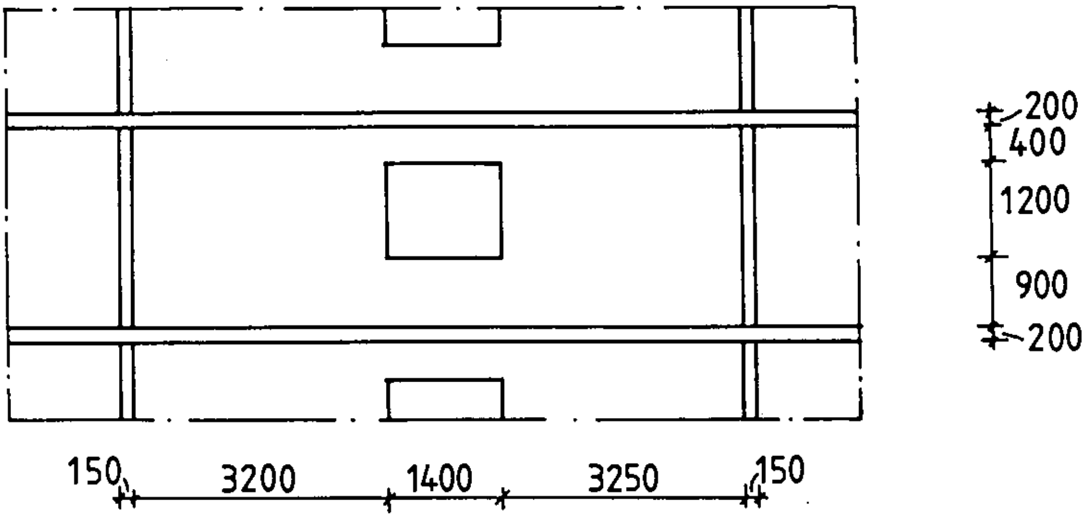


Figure 2.2 Section of the Teknikern building.



Section A-A (South-east facade)



Section B-B (North-west facade)

Figure 2.3 Facades of the Teknikern building.

Table 2.1 Thermal properties of building fabric, the Teknikern building

	Thick-ness mm	Conduc-tivity W/m,K	Density kg/m^3	Specific heat J/kg,K	Thermal resistance m^2,K/W
INTERNAL WALL 150 mm					
Concrete	150	1.50	2300	880	
INTERNAL WALL 100 mm					
Gypsum	13	0.46	900	1090	
Cavity	74	-	-	-	0.05
Gypsum	13	0.46	900	1090	
EXTERNAL WALL					
Concrete	40	1.74	2300	880	
Insulation	70	0.040	150	880	
Concrete	40	1.74	2300	880	
BASEMENT FLOOR					
Concrete	250	1.74	2300	880	
Ground	-	1.15	1400	1670	
SLABS					
Concrete	200	1.50	2300	880	
INNER ROOF					
Top					
Min.wool	200	0.040	150	880	
Concrete	200	1.74	2300	880	
Bottom					
OUTER ROOF					
Top					
Asph.roofing					0.03
Board	20	0.14	340	1300	
Bottom					

Table 2.1 Thermal properties...... (cont'd)

	Thick- ness mm	Conduc- tivity W/m,K	Density kg/m^3	Specific heat J/kg,K	Thermal resistance m^2,K/W
EXTERNAL DOOR					
Inside					
Board	12	0.14	340	1300	
Cavity	20	-	-	-	0.05
Wood panel	12	0.14	500	2720	
Outside					
BASEMENT WALLS					
Concrete	250	1.74	2300	880	
BALCONY					
Concrete slab	200	1.74	2300	880	
Concrete barrier	100	1.74	2300	880	
Concrete partition	50	1.74	2300	880	

Table 2.2 Infiltration and ventilation in the Teknikern building

	Infiltration (m^3/h)	Ventilation (m^3/h)
Attic	300.0	-
Per room	10.0	50.0
Basement	85.0	425.0

Table 2.3 Internal load per room in the Teknikern building

Hour	Load (W)
0 - 06	250
06 - 07	750
07 - 16	250
16 - 17	1000
17 - 20	400
20 - 24	250

APPENDIX C
WEATHER DATA SPECIFICATIONS

Two sets of weather data have been used in this work. It should be noted, that both of these were prepared for this special task, and the data should not be used without care for other purposes.

The main characteristics of the weather data are given in Table 1 and Table 2. In these tables, the degree-hours are defined by

$$Q = \int_{\mathrm{month}} \max\left\{(\vartheta_{\mathrm{room}} - \vartheta_{\mathrm{out}}), 0\right\} \, dt$$

All values given in the tables are calculated from the hourly values on the weather tape specified in this appendix.

Table 1 Main characteristics of the weather data in Vetlanda, November 1976 - April 1977

Month	Mean outdoor temp. (°C)	Degree-hours (°C·h/month) $\vartheta_{room}=$		Solar radiation on the horizontal plane (Wh/m^2,month)	
		16 °C	20 °C	Diffuse	Global
Nov	1.57	10390	13270	8904	12046
Dec	-4.36	15148	18124	5589	6158
Jan	-3.44	14462	17483	8377	10909
Feb	-4.74	13935	16623	17448	21367
March	-0.27	12105	15081	30282	52954
April	1.95	10114	12994	44073	70835

Table 2 Main characteristics of the weather data in Stockholm 1971

Month	Mean outdoor temp. (°C)	Degree-hours ($^{\circ}C \cdot h$/month) ϑ_{room}= 16 °C	20 °C	Solar radiation on the horizontal plane (Wh/m^2,month) Diffuse	Global
Jan	-0.93	12598	15574	6637	10813
Feb	-1.40	11692	14380	12783	21844
March	-2.06	13438	16414	27626	54639
April	3.45	9034	11914	45077	102746
May	11.47	3568	6345	61281	170555
June	14.88	1176	3704	69479	176139
July	17.74	525	1858	66723	169503
Aug	16.47	514	2666	52864	132942
Sept	10.73	3792	6672	36340	75170
Oct	7.31	6467	9443	18714	42409
Nov	0.97	10823	13703	8819	17616
Dec	1.01	11154	14130	4606	8020

WEATHER TAPE SPECIFICATION

The weather tape contains four files:

1. Weather data for the Vetlanda house. November 1, 1976 - April 30, 1977, measured on site (181 blocks, a total of 4.344 records).
2. Weather data for the Teknikern building. January 1, 1971 - December 31, 1971 from Stockholm (365 blocks, a total of 8.760 records).
3. Identical to file 1.
4. Identical to file 2.

The tape contains some calculated values in addition to the measured values. The tape should not be used for purposes other than the work in this annex.

Record format

9-Track, Odd Parity, 800 bpi, no label.

Data is encoded as card images, one byte per EBCDIC character, one 72 character card per hourly record.

The records are blocked into days with 24 records per block.

A standard tape mark is recorded at the end of each file and two at the end of the fourth file.

Card format

Field	Columns	Item	Unit
1	1-4	Dry bulb temp.	0.1 °C
2	5-8	Dew point temp.	0.1 °C
3	9-11	Wind direction	Degree from north
4	12-14	Wind speed	0.1 m/s
5	15-16	Weather (ww)	
6	17	Weather last hour (W)	
7	18	Cloudness (N)	Eights
8	19-20	Sunshine duration	0.1 h/h
9	21-25	Global radiation on horizontal	0.1 $Wh/h,m^2$
10	26-30	Diffuse radiation on horizontal	0.1 $Wh/h,m^2$
11	31-35	Direct normal radiation	0.1 $Wh/h,m^2$
12	36-40	Solar altitude	0.001 radians
13	41-45	Solar azimuth	0.001 radians from north
14	46	Snow	
15	47-62	Blank	
16	63-66	Year	
17	67-68	Month	
18	69-70	Day of month	
19	71-72	Hour of day	

Common remarks

All items are written as integers, with negative values signed.

Notes on the usage of units

> 0.1 °C means that the last digit in the four columns field is tenth of degrees.

Except for the fields without available data, see below, values are given for each hour and no action for missing values should be necessary. "From north" is counted over east - i.e. east is 90° etc.

Remarks on weather data for Vetlanda

Fields 2, 3, 5, 6, 7 and 8 are not available and blanked out.

Fields 1 and 4 are instantaneous values.

Field 14 is set to 1 if the ground is covered by snow, else it is set to 0.

Latitude is 57.42 degrees north.

Longitude is 15.08 degrees east.

Reamrks on weather data for Stockholm

Field 14 is not available and blanked out.

Fields 1, 2, 5 and 7 are observations close before indicated time.

Fields 3 and 4 are mean values from 10 minutes preceding indicated hour.

Latitude is 59.33 degrees north.

Longitude is 18.03 degrees east.

Remarks on solar data

Fields 8, 9 and 10 are values integrated during 60 minutes preceding the indicated hour.

Field 11 is calculated from values in fields 9, 10 and 12.

Fields 12 and 13 are calculated for the indicated hour. In case of negative altitudes both fields are set to zero.

Remarks on hour of day

The hour of day goes from 1 to 24 and refers to mean European time, equal to Swedish Standard Time.

Time meridian is 15.0 degrees east.

Remarks on wind direction

The wind direction is defined as the direction from which the wind blows. North direction is indicated as 360, direction 0 is used for calm weather.