The solar house of the Eindhoven University of Technology

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24. THE SOLAR HOUSE OF THE EINDHOVEN UNIVERSITY OF TECHNOLOGY

BY

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1. INTRODUCTION

The recently completed Solar House of the Eindhoven University of Technology (*fig. 1*) is the result of more than three years of research and development work. At the beginning of 1973 an exploratory study was made [1], which led to the then rather unexpected conclusion that, even in the Dutch climate, the sun could be considered as a viable source of thermal energy. Particularly when the prices of the conventional energy sources, namely oil and natural gas, were bound to rise in the future.

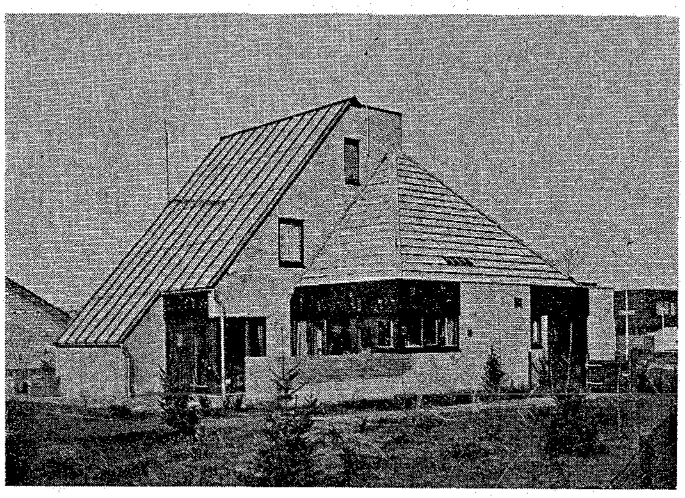

Fig. 1. — South-East view of solar House

As such a rise was to be expected, due to the gradual depletion of the gas and oil fields, the study ended with the recommendation that research on the application of solar energy for heating purposes should be started on a modest scale.

It was clear from the start that in the follow-up of this recommendation both architectural and mechanical engineering problems would have to be solved. The already existing co-operation between the Departments of Mechanical Engineering and Architecture was therefore taken as the basis for the further research and development work. The idea to build a solar house, with the aim of carrying out the scientific research in the practical dimensions which are essential for all technology, grew up out of this co-operation.

Three years is a rather short period of preparation for a field experiment in a new area of research. Such a fast realization of the solar house would have been impossible without the data on solar heating installations already existing in other countries (Australia, U.S.A., Israel).

A strong effort of our own however was indispensable for the *translation* of these data to meet conditions in The Netherlands. In this connection the customary styles of living and building play their role, but the different and generally unfavourable climatic conditions in The Netherlands play an even greater role. The fact that the current data on solar radiation are ill-suited for the design of solar heating installations actually proved to be the biggest handicap in the *translation*, and even now this handicap has only partly been overcome. Therefore a separate investigation has been started recently at the EUT, with the aim of obtaining more suitable insolation data.

2. THE SOLAR HEATING SYSTEM

Figure 2 is a sketch of the solar heating system.

Important parts of this system are :

- the solar collector, which transform solar radiant energy into heat,
- the watertank storage in which momentarily surplus heat can be stored for low radiation periods,
- the gas-fired auxiliary boiler, which supplies heat during prolonged low radiation periods, and
- the heating system, which distributes the heat in the dwelling house.

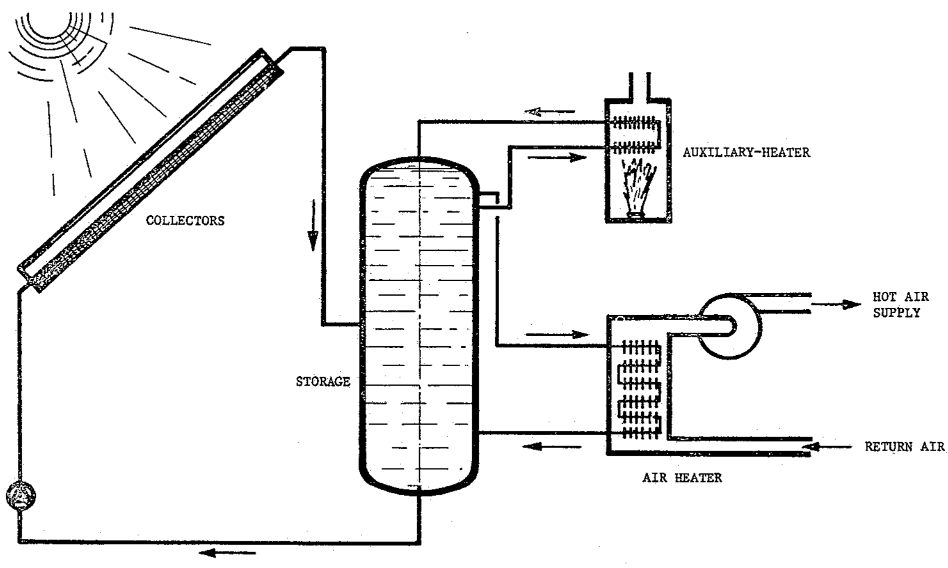

Fig. 2. — Simplified scheme of the solar heating system

The solar collectors

The construction of the collectors is shown in *figure 3*. The most important parts of the collector are the absorber plates ; for this solar house, these plates are designed as one-piece radial finned aluminium tubes (*figure 6*).

The outside of the finned-tube collector plates is provided with a selective absorber coating. This consists of chrome-oxide and has the property of absorbing solar radiation (to about 92 % ; the collector looks black) and decreases the heat radiation from the plate to the glass cover (plate emittance for heat radiation is less than 15 %). The width of the finned-tubes is 150 mm. The whole solar-roof surface consists of forty parallel finned-tubes with lengths of 9 metres and 7,5 metres (see *figure 1*).

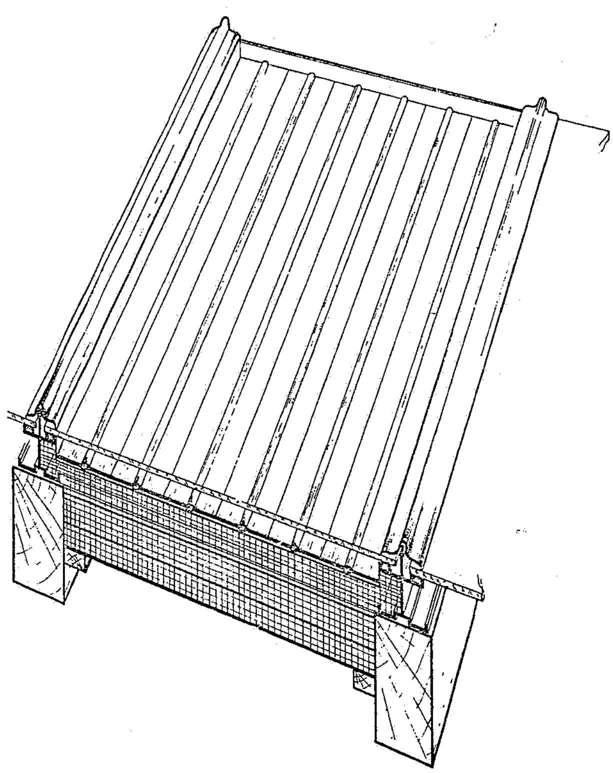

Fig. 3. — Construction of the collectors on the solar roof

The net collector surface amounts to 51 m^2. Water is pumped through the tubes from the bottom to the top of the collector and transports the absorbed energy to the watertank.

The pump is controlled automatically by the difference in temperature between sensor elements applied to the finned-tube and to the bottom of the storage tank.

The glass cover in front of the finned-tubes serves to prevent the collected heat from escaping to the environment. It also protects the tubes, especially the vulnerable selective coating against weather influences and dust from the atmosphere. According to experience, dust falling on the glass covers, is normally removed by the rain.

Figure 3 shows the covers fitted on aluminium support rails. This type of rail is frequently used for greenhouses. The rails are carried by wooden beams supporting the solar roof. The rails are fixed on the beam in the middle and are freely sliding at both ends to provide room for thermal expansion. This expansion may amount to 2 cm.

Noteworthy is the *solar roof* which does not consists of separate collector boxes with a water supply and exhaust each, but forms an integral parts of the roof structure in this solar house.

It is to be expected that the cost of a solar roof will be reduced if the roof is designed as an integral whole instead of a large number of relatively small collectors assembled on the roof.

Aluminium protecting sheets are mounted behind the finned-tubes, and behind these sheets there is an insulation 12 cm thick.

The insulation prevents nuisance to the occupants, because the tubes reach high temperatures (sometimes over 150 °C). For further technical details concerning this solar roof we refer to [2].

The watertank storage

The storage of temporarily surplus heat takes place in a watertank of 4 m³ content. This watertank is shown in *figure 4*. In order to utilize the heat as well as possible, special attention has been given to the design of the storage tank, and particularly to the thermal stratification of the water.

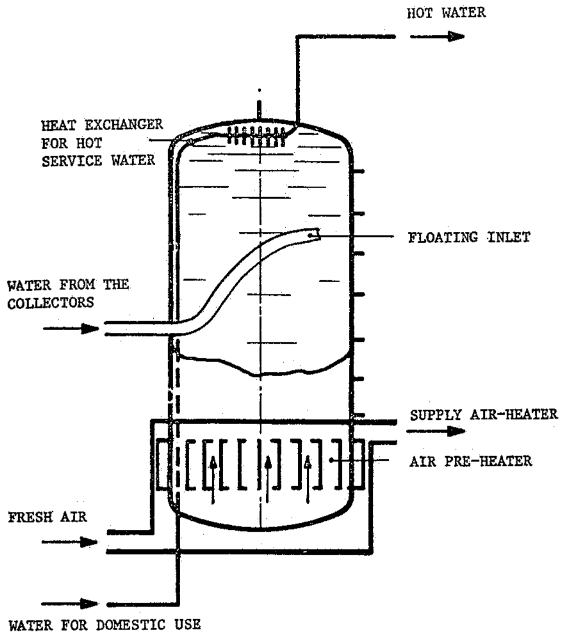

Fig. 4. — Scheme of the watertank storage with a floating inlet, a heat exchanger for hot service water and an air pre-heater

Thermal stratification means the highest temperature at the top and the lowest at the bottom of the tank. The temperature increasing gradually from the bottom to the top.

The water from the collector has an alternating temperature because of the fluctuating intensity of the solar radiation. The water coming from the collectors is always supplied to the level in the tank where the temperature is equal to that of the water from the collectors by the use of a floating inlet (a flexible thin walled plastic hose). The temperatures and the use to which the water can be put at these temperatures are preserved in this way. The floating inlet makes 5 % more energy available to the whole solar heating system. Besides there is a possibility of reducing the dimensions and costs of some parts of the solar heating system.

The hotwater supply of the dwelling can be provided with a coil shown in *figure 4*. The water that is to be heated flows through the coil from the bottom to the top and reaches a temperature close to the top tank temperature. The auxiliary heater does not allow the latter temperature to drop below 50 °C.

A casing is mounted around the lower part of the watertank; fresh air for the dwelling flows through it. The air is heated in it and the water in the bottom is cooled simultaneously. The temperature of the water flowing to the collector is kept as low as possible in this way, which increases the efficiency of the collectors, see [11]. The improve the heatflow from the tank to the air, thin fins are fixed on the bottom part of the tank. This yields an additional 5 % of energy for the whole solar heating system.

The capacity of the heat storage is enough to heat the house for two days with average winter weather. It would be technically possible to use a larger watertank with a greater storage capacity. Particularly in the transition seasons the output of the solar heating system would be increased; however the extra cost of greater storage (about Dfl. 500,— for each m³ extra) does not bring a commensurate increase in heat output.

The auxiliary heater

The auxiliary heater does not allow the water temperature at the top of the tank to drop below 50 °C. *Figure 5* shows how the auxiliary heater is connected to the storage tank.

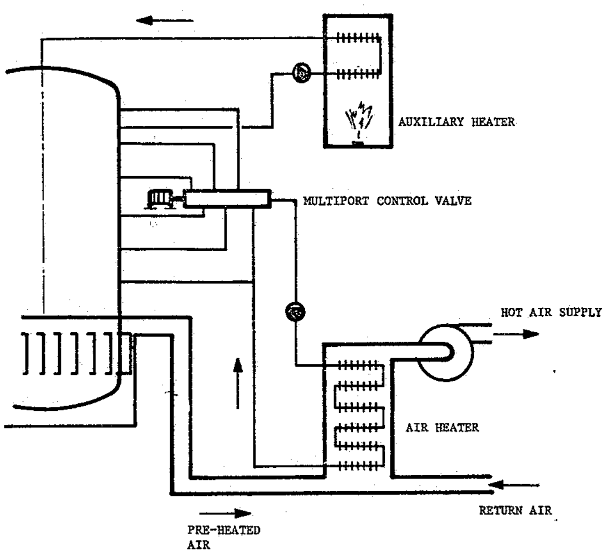

Fig. 5. — Auxiliary heater, heat supply system and air heater (Schematically)

The temperature at the top of the tank is controlled by means of a thermostat fitted 0.5 m from the top of the tank, which switches the auxiliary heater (a normal gas-fired boiler) on or off at switching temperatures of 50° and 60 °C respectively. This hysteresis is necessary to give the boiler longer burning periods (about 3 min.). The start and stop losses can be reduced in this way.

Frost protection

With frosty weather the water in the finned-tubes will freeze in dark cloudy weather and by night. Precautions must be taken to prevent the finned-tubes from being damaged by the expansion caused by the freezing.

The most common methods of frost protection are :

— draining the collector,

— adding glycol to the water in the collector.

The first method could not be easily applied because the lowest part of the collector is lower than the top of the storage tank.

The disadvantage of the second method is the necessity of a partition heat exchanger, which involves extra costs and decreases the heat gain of the solar heating system (with 5 to 10 %).

Therefore a completely new method of frost protection is applied, which is shown in *figure 6*.

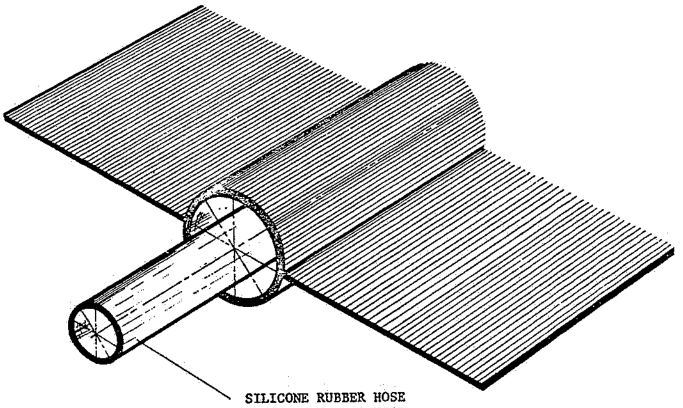

Fig. 6. — Frost Protection of the finned-tubes

A silicon rubber hose, filled with glycol, is placed inside the finned-tubes. The hoses are all connected with a small expansion vessel outside the water system. The hose inside the tube is squeezed flat when the water freezes and the glycol flows to the expansion vessel. The experience gained with this system in the winter 1976/77 was positive, and no damage to or leakage from the finned-tubes did occur.

The described frost protection system is not a universal solution to the freezing problem. It is only applicable in the finned-tubes or in a similar type of absorbing plate, and involves rather much mounting work.

In the given situation it was the most suitable solution. General application of this system requires further development.

Thermal insulation

It is obvious that all the pipes of the solar heating system and the watertank containing hot water are well insulated.

The insulation of the watertank consists of rockwool with a thickness of 10 cm.

The suspension of the pipes and the support of the watertank are specially constructed to diminish heat leakage via the connection elements.

To reduce these losses the number of suspension points is reduced as much as possible and insulation is fixed between pipes and connection elements.

The heat supply system

A conventional hot air system distributes the warm air over the rooms in the dwelling. An unusual feature is the design of the airducts to prevent air leakage, which adds to the accuracy of the measurements. Airheating was preferred to radiatiorheating or floorheating, because the dwelling is made draughtfree. This building method was essential to reduce the total energy demand of the dwelling ; however it may make the ventilation inadequate in a calm wind. So for both hygienic and safety reasons it is very desirable to apply forced ventilation in a draughtfree house. An airheating system is readily combined with forced ventilation.

The air distribution system of a solar heating system must function at the lowest possible temperature level [11]. The average of the supply and exhaust heating medium temperature being the decisive quantity. In this solar house heating system this average temperature is about 30 °C, as the air supply temperature does not normally exceed 40 °C. The number of revolutions of the fan supplying the air to the dwelling can be increased when the outside temperature falls below zero.

With a hot air system it is possible to respond to rapid fluctuations in the heat demand of the house by controlling the air supply temperature. This also was a reason to prefer airheating. It is generally known that well-insulated houses respond acutely to e.q. alternating insolation.

The heat from the watertank storage is transferred to the air in an air-water heat exchanger. *Figure 5* shows how this transfer occurs. The water supply temperature from the watertank is restricted to the lowest temperature necessary for maintaining the room temperature. The control system makes use of the thermal stratification of the watertank storage.

Five supply pipes for the airheater are connected to the watertank at various levels. Further the pipes are connected to a control cylinder. Any difference between the room temperature and the set point causes the servomotor to turn the control cylinder to a higher or lower outlet port in the watertank. The adjustment of the control cylinder stops when the difference between setpoint and room temperature equals zero.

The performance of this control system in the winter 76/77 has been excellent ; the room temperature was almost constant and furthermore the use of heat from the watertank was very efficient. For further detailed information about this system see [4], [5] and [6].

3. THE HOUSE

The house is fully adapted to the solar heating and the measuring system. This in order to make clear observations and a correct judgement about the potential of solar heating possible. An experimental solar house differs from a conventional house in the following respects :

— Provisions must be made to accomodate the piping and the measuring cables and space must be provided for the watertank storage and measuring instruments ;

— The house must be designed and constructed with an open mind towards energy conservation ; i.e. it has to be built draugh-free and well insulated in order to approximate the ratio between the heat gain of the solar installation and the heat demand of future houses as close as possible ;

— The solar roof must be integrated in the architectural design without loss of functional use of the inside space ; the existing building codes have to be observed as well.

The first-mentioned provisions are described in the previous chapter. Additionally it is worth noting that the beams are made out of laminated wood to prevent deformations by the relatively high temperatures caused by the collector. On the ground floor a floorspace of about 7 m² and on the first floor an attic space of about 18 m² is reserved for the water-tank storage and the measuring units.

More than 50 % of the attic area serves the measuring units and can be saved in the future solar heating systems.

Particular attention has been given in the design and construction to good thermal insulation ; the reasons for this have already been outlined before.

To reduce the heat transmission through the outside walls, the width of the cavities has been increased from the usual 5 cm to 8 cm and glass-wool with a thichness of 7,5 cm has been inserted. The heat transmission coefficient obtained in this way equals 0.4 watt/m² °C*.

The roof surfaces also have a heat transmission coefficient of 0.4 W/m² °C ; specially manufactured roof boards are used for this purpose (see *figure 7*). The underside of the groundfloor is insulated with 4 cm of glaas-wool (see *figure 4*).

It is self-evident that doublepane windows are used throughout the house.

The window areas are relatively small and mainly concentrated on the south face, as can be seen in *figures 1* and *8a, b*. The window area on the west, east and north face is restricted to the area required for inside space illumination.

In this context it may be interesting to note that in the Dutch climate double pane windows on the

(*) For comparison: The recently improved building codes require a heat transmission coefficient of 0.78 W/m² °C; the value for the conventional Dutch cavity wall is 1.4 W/m² °C.

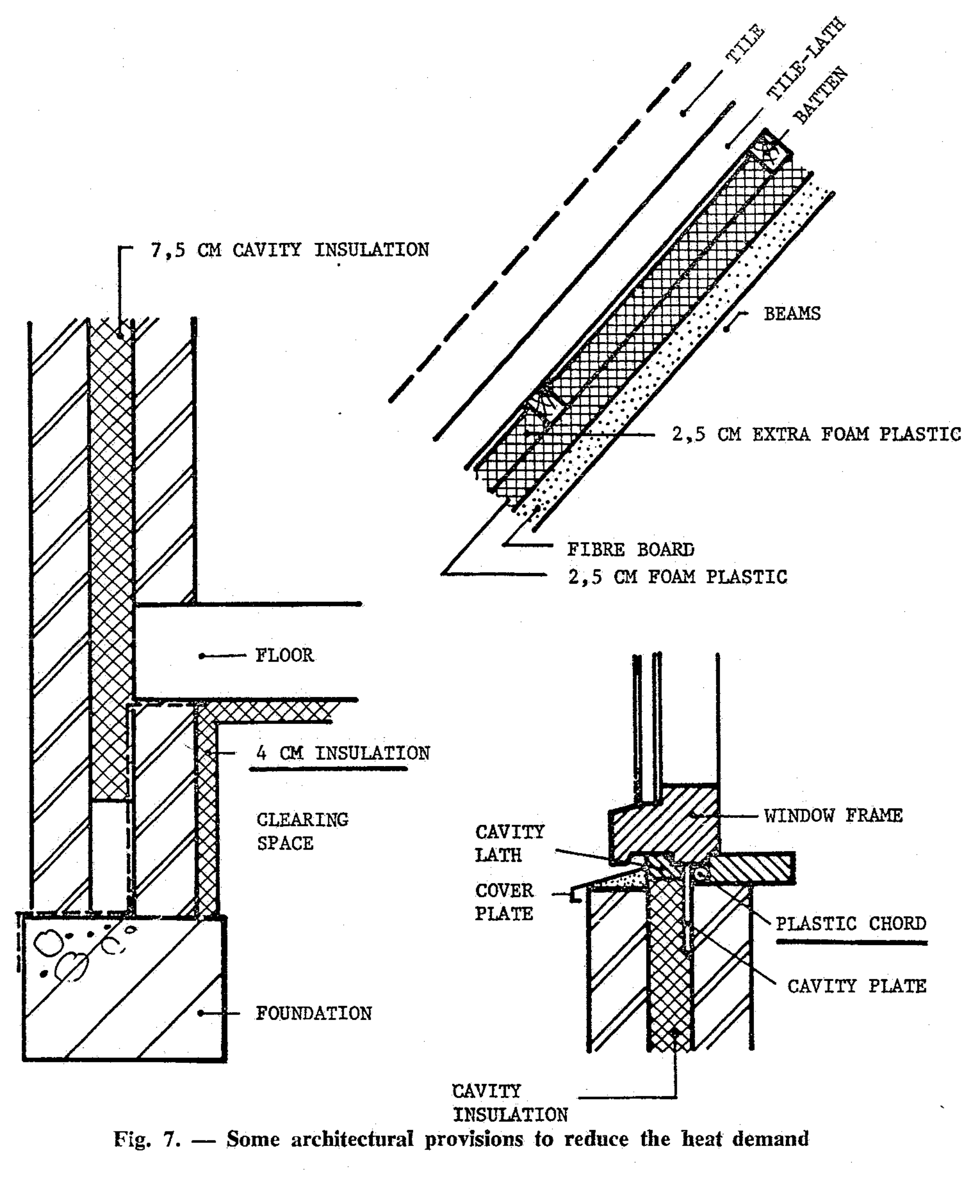

Fig. 7. — Some architectural provisions to reduce the heat demand

south face absorb more light energy during the heating season than the thermal energy losses effected by them. From an energy point of view it is therefore recommendable to install spacious (double pane) windows on the south face.

As remarked before, much attention has been given to a draught-free construction of the house. For this purpose a specially designed draught-free construction is applied to all the window-frames. The construction is shown in *figure 7*. All doors and other moving elements in the outer walls are provided with anti-draught strips. The connection between roof and brickwork has been filled with draught-tight insulation material.

It is intended to check all these provisions to prevent draught by means of measurements.

According to calculations the provisions mentioned above reduce the heat demand of the house to 11 kW at an outside temperature of − 10 °C and an inside temperature of 20 °C. This is a very low demand compared with conventional Dutch standards, especially for a house with a volume of about 800 m^3 (living area 220 m^2).

The integration of the solar roof in the architectural design of the solar house was the third aspect mentioned in the beginning of this chapter. Since the solar house was the first one in The Netherlands with an integral design, an entirely new architectural concept has been developed. The dimensions, inclination, material and the function of the solar roof together with the conventional requirements as to residential design form the elements of the new synthesis. The quality of this synthesis is subject to personal judgement in the last resort.

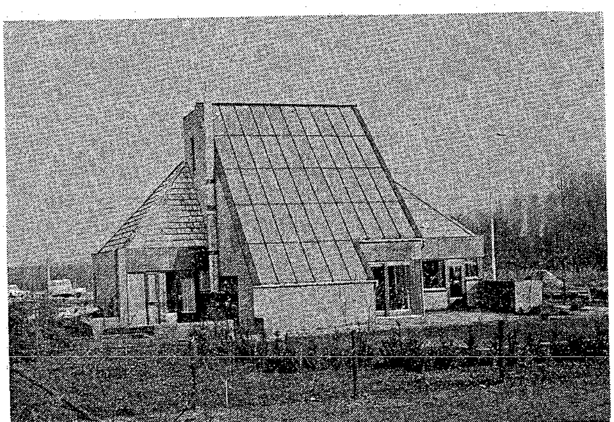

Fig. 8 a. — South-west view of solar house

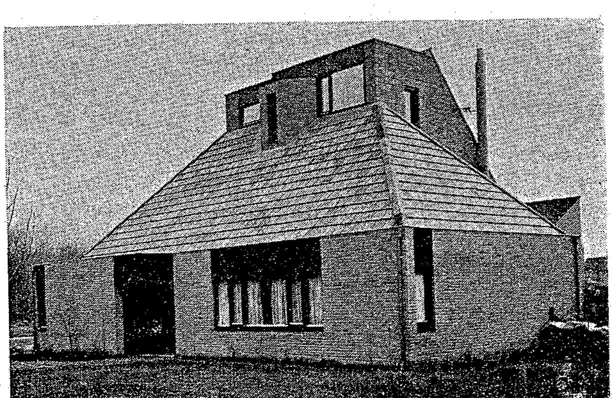

Fig. 8 b. — Nort-west view of solar house

4. RESEARCH PROGRAMM AND MEASURING SYSTEM

For the next few years the research will be concentrated on the performance of the solar heating system. As this performance is related to the heat demand of the house, this demand will also be measured. However, these measurements will be of a general character. A number of measurements will be carried out in order to check the insulation. The measuring points in the solar heating system and the house total up to 50. In this paragraph the measuring system is described further, starting from the objectives of the research programme. Further details are given in [8].

The most important meteorological input datum for the performance of the solar heating system is the intensity of the solar radiation. This is measured with two solarimeters (see *figure 9a*), both mounted in the plane of the solar roof surface and one of them behind a glass cover, in order to check the transparency thereof. Since the solarimeters must be cleaned frequently they have been mounted within easy reach from the ground.

A thermo sensor (PT 100) is suitably affixed outside the dwelling for measuring the ambient temperature. The velocity and the direction of the wind are measured by means of an anemometer, placed 1.5 m above the highest point of the roof.

The heat gain of the collector is calculated from the difference between inlet and exhaust medium temperatures and the amount of water flowing through the collector.

The pump of the collector-circuit has a constant flow and the amount of flowing water can be calculated from the duty times of the pump. Six PT 100 temperature sensors are fixed on the finned-tubes in order to check the performance of the collector and the theoretical models. In the watertank storage, the inlet- and outlet flow and the temperatures at eight different levels are measured. The latter to follow the thermal stratification changes in time.

The temperature rise of the fresh air when flowing along the bottom of the watertank storage is measured as well.

Because a large amount of service water flows incidentally through the heat exchanger in the watertank storage, it will be necessary to measure continuously the amount of hot service water, and its temperature.

The duty time, inlet and outlet temperatures of the auxiliary heater are continuously measured to calculate the energy supply. The gas-consumption of the gas-fired boiler is noted daily to check the last calculations.

The amount of heat supplied with the heating system to the dwelling is proportioned to the amount of

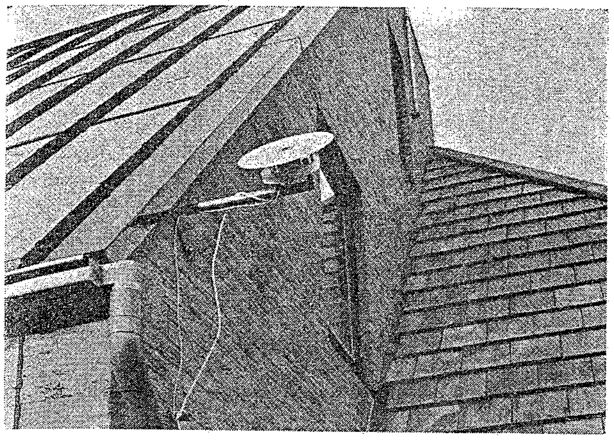

Fig. 9 a. — Solarimeter

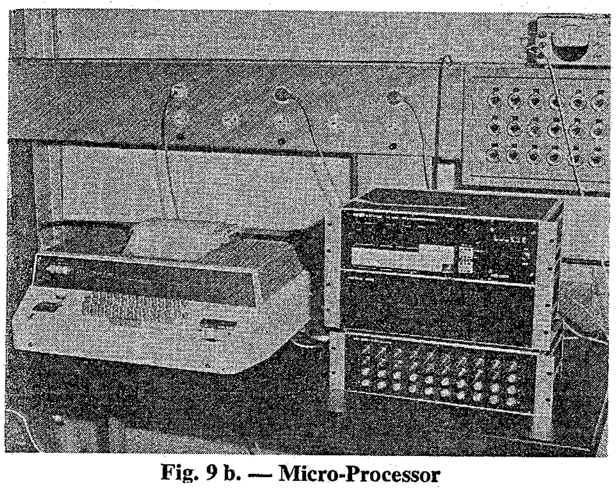

Fig. 9 b. — Micro-Processor

water flowing through the air-water heat exchanger and the water temperature difference between the inlet and outlet of the air-water heat exchanger. The data are all gathered for the further required calculations.

The heating for the house is partially obtained from the electricity and gas used in lighting and cooking, etc. It is necessary to estimate this amount of heat. The gas and electricity consumption therefore is noted daily.

In addition the duty time of the exhaust ventilation of the kitchen is noted since the associated heat loss from the house may be considerable.

Since the climatic conditions in The Netherlands are subject to rapid change, a large part of the foregoing measurements must be frequently repeated. Otherwise it will be impossible to follow the dynamic behaviour of the solar heating system.

The measuring system produces 72 000 measuring data every day when 50 measuring points have to be read per minute. It is impossible to work these data all out by hand and impraticable to punch them on tape. Therefore a micro-computer has been applied to reduce these data to practical limits and to make simultaneous heat balance calculations in addition.

This micro-computer gives a read-out every half hour on a teletype and is connected by telephone to the university. The teletype prints the main data and also gives punched-tape information.

The object is to follow carefully the behaviour of the solar heating system for three heating seasons. The solar heating system can be analysed with this measuring system for all weather conditions to be expected in this country. The following weather conditions are e.g. possible : glazed frost, hoar frost, snow, rain, strong wind from various directions, frost, etc. A reliable basis for the design and development of solar house heating systems can be obtained in this way.

An additional important research objective is the behaviour of the system in practice (reliability, corrosion, lifetime, etc.), which demands continuous observation.

5. THE PERFORMANCE OF THE SOLAR HEATING SYSTEM

The performance of the solar heating system is presented in this chapter, as deduced from calculations and experiments. The results are preliminary as further experients are still going on to determine accurately the performance of all the units involved. However the properties of solar heating systems have become well enough known by now to allow a good first impression to be obtained from the given results.

The calculations are based on hourly meteorological data of the KNMI De Bilt. These data were already available at the start of this research project because there already was a research programme at the EUT for into the influence of insolation, ambient temperature, wind velocity, etc. on the climate in houses and buildings. The average meteorological readings covering the last ten years were available on tape. In addition a computer programme which had been adapted to calculate the yield of the solar house heating system and the heat needed for the house was also available. The total amount of heat over a month, heating season or whole year, could thus be determined.

Not all the influences are covered by this program, the calculations would in that case have been to time-consuming. For instance the reflection of radiation from the ground, small heat losses that can occur in parts of the solar heating system, shadow thrown by other buildings and trees in the neighbourhood of the house ; effect of snow on the solar roof, melting of hoar-frost in the morning, etc. are not included. More over a number of other influences are described by rough estimates ; such influences are the heat production from the use of electricity, human bodies, cooking, the heat losses by natural ventilation, the heat needed for the domestic hot water.

Approximations and omissions will cause some differences between calculations and measurements. It appears from comparison that these differences remain within acceptable limits.

Figure 10 shows the calculated performance of the solar heating system over a year in a cold winter and again in a mild winter. For the cold winter the winter of 62/63 was taken and 67/68 for the mild winter.

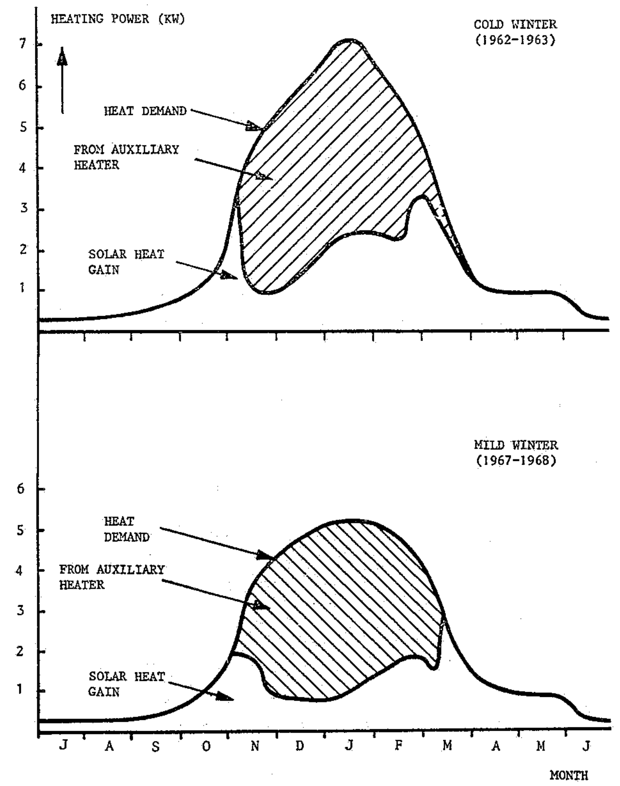

Fig. 10. — Calculated performance of the solar heating system in a year with a cold and a year with a mild winter

The non-shaded surfaces in figure 10 show the amount of heat delivered by the solar heating system. The shaded surface in the bell-shaped diagram is the amount of heat delivered by the auxiliary unit.

The bell-shaped diagram itself gives the required amount of heat for the dwelling including the hot water for domestic use and corrected for the amount of heat from electricity, cooking, human bodies and insolation via the windows.

In [9] more detailed information is given about the proportions of these influences.

It is to be expected that the heat needed for the house in a cold winter is greater than in a mild one as *figure 10* shows. The performance of the solar heating system is however greater in a cold winter, because there is a greater number of insolation hours. The results of the calculations give the amount of heat needed for the house as 23 400 kWh for the cold winter of which the solar heating yields 10 700 kWh.

In the year with the mild winter these results are resp. 19 500 kWh and 8 750 kWh. The saving in natural gas in both years is considerable, namely 53 % ; 7 % of saving are achieved by switching off the auxiliary unit during the long summertime. The idle time losses of a gas-fired boiler for hotwater can be eliminated in this way. Calculated for an average year, the latter savings amount to about 2 000 m³ of natural gas.

The curves of *figure 10* that show the heat needed for the house are smooth. This is due to the fact that the curves are plotted on the monthly average. Actually, however, there are day-to-day variations in the heat requirements for the house and in the heat delivered by the solar heating system. These variations are shown in figure 11. This diagram shows the heat needed for the house and the heat delivered by the auxiliary unit from day-to-day and the heat content of the watertank storage at the end of the day. This is calculated on hourly data for the period from mid-October to mid-April of an « average year » worked out by the EUT [10].

In addition to the great variation from day to day, *figure 11* also shows the heat content of the watertank storage dropping to zero at the beginning of November. In November the winter situation gra-

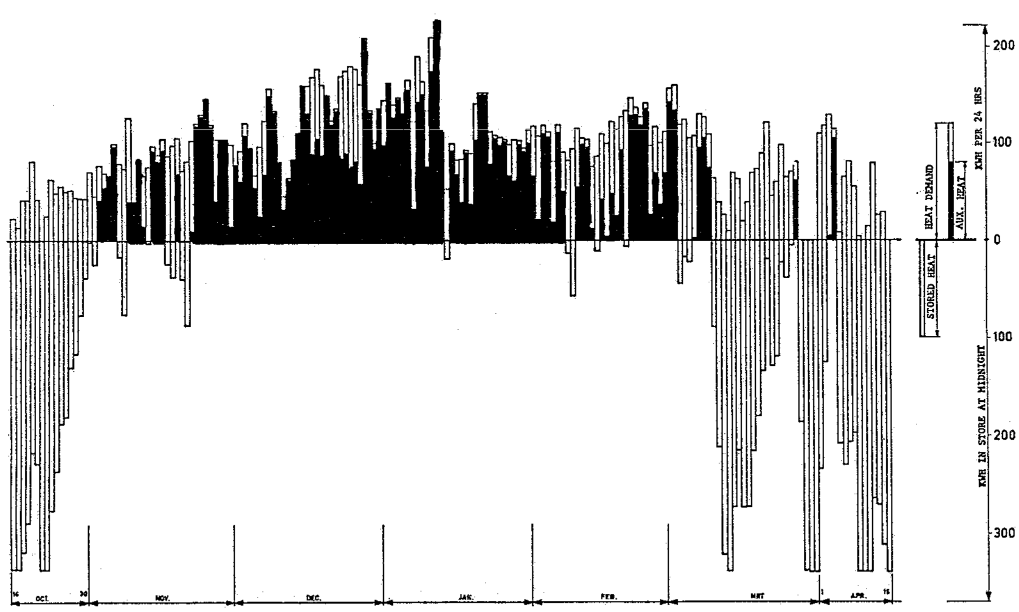

Fig. 11. — Day to day heat economy of the solar house (Calculated for the dutch reference year)

dually sets in and here the auxiliary heater has the larger part to play and a heat surplus is only incidentally supplied to the watertank storage. From Mid-February to the end of March there is a period of heat surplus giving a full watertank storage and then the auxiliary heater is hardly even necessary.

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