PERFORMANCE OF THE ZERO ENERGY HOUSE IN DENMARK

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SEPTEMBER 1977

MEDDELELSE NR. 64

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ABSTRACT

The paper describes the performance of the Zero Energy House project during the period 1976-77. With energy conservation arrangements such as high-insulated constructions, mobile insulation of the windows and heat recovery in the ventilating system the heat requirement for space heating was calculated to 2300 kWh per year. During the winter period 1976/77 the heat requirement, however, was measured to 5800 kWh. The main reason for this difference is an unintentional infiltration and a bigger rate of mechanical ventilation than originally calculated. The solar heating system consists of a 42 m^2 flat-plate solar collector and a seasonal water storage tank with a capacity of 30 m^3. This system was dimensioned to cover the heat requirement for space heating and hot water supply during the whole year. Due to a very small amount of solar radiation last winter and due to the bigger heat requirement for space heating, the solar heating system has covered only about 43% of the heat requirement.

Paper presented at
1st German Solar Energy Forum 26.-28. September 1977, Hamburg.

Introduction.

During the spring 1975 a one-family, one-story, experimental house, the Zero Energy House, has been constructed at the Technical University of Denmark.

The installation of the measuring equipment was finished in December 1975,

During the winter 1975/76 the house has been occupied periodically by members from the research group.
Since October 1976 the house has been occupied by a typical Danish family: Two adults and two children at school.

The measurements will continue during the winter period 1977/78 without occupation. After this period the house will be used as a guest house for the Technical University.

Description of the building.

The house is designed as two dwelling units of 60 m^2 each, separated by a glass-roofed atrium of 70 m^2. The atrium is not heated, but it is protected against wind and rain, and therefore it may be used as a part of the living area at day time during the main part of the year.

The two dwelling units are constructed of prefabricated units with 30 cm of mineral wool in the walls and 40 cm of mineral wool in the roof and in the floor.

The windows are provided with two layers of glass and with insulated shutters to increase the insulation value during the night. The windows facing south are furthermore provided with a sun shading device.

Heat recovery equipments are installed in the ventilating system with an efficiency of 80% and in the waste water system with an efficiency of 50%.

The south facing upper vertical part of the atrium contains a flat-plate solar collector of 42 m^2. The solar collector is connected to a water storage tank of 30 m^3 buried in the ground just outside the atrium.

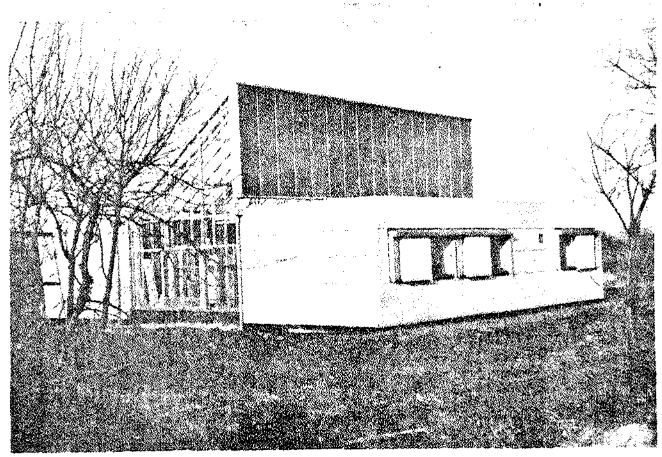


Figure 1 The Zero Energy House.

Description of the measurement system.

The measurement system is divided into 5 sections:

Analoge measurements in the house (indoor temperatures, temperatures on the windows and insulated shutters, temperatures in the heat recovery system).

Digital measurements in the house (opening of windows and doors, operating of insulating shutters, heat flow measurements, operating hours of the heating units).

Analoge measurements in the solar heating system. (temperature in the solar collector and the storage tank).

Digital measurements in the solar heating system (heat flow measurements, operating hours of solar collector).

Meteorological measurements (outdoor temperature, solar radiation on a vertical and horizontal surface).

The measurements are registered by a Solartron Datalogger with 70 channels.

The channels registrating the operation of the solar heating system and the meteorological data are scanned each 10 min., the other channels are scanned each hour.

Energy consumption for space heating.

With the energy conservation equipments: High-insulated constructions, mobile insulation of the windows and heat recovery in the ventilating system, the heat requirement for space heating has been calculated to 2300 kWh in the Danish Reference Year.
During the winter term October 1, 1976 till May 31, 1977 the heat requirement for space heating has been about 5800 kWh, more than twice as great as originally calculated.

Among other things this is due to the fact

1) that the house has not been as tight as assumed (infiltration is measured to 0.15 air change/hour against assumed 0.03 air change/hour). This is about 10% of the difference between calculated and measured energy requirement.
2) that the mechanical amount of ventilation has been greater than assumed (240 m^3/h through all 24 hours against assumed 100 m^3/h during the night and 200 m^3/h during the day).
   The degree of heat recovery in the ventilation system has been about 0.7 against assumed 0.85. This is totally about 60% of the difference between calculated and measured energy consumption.
3) that the transmission loss among other things through the shutters has been greater than calculated.

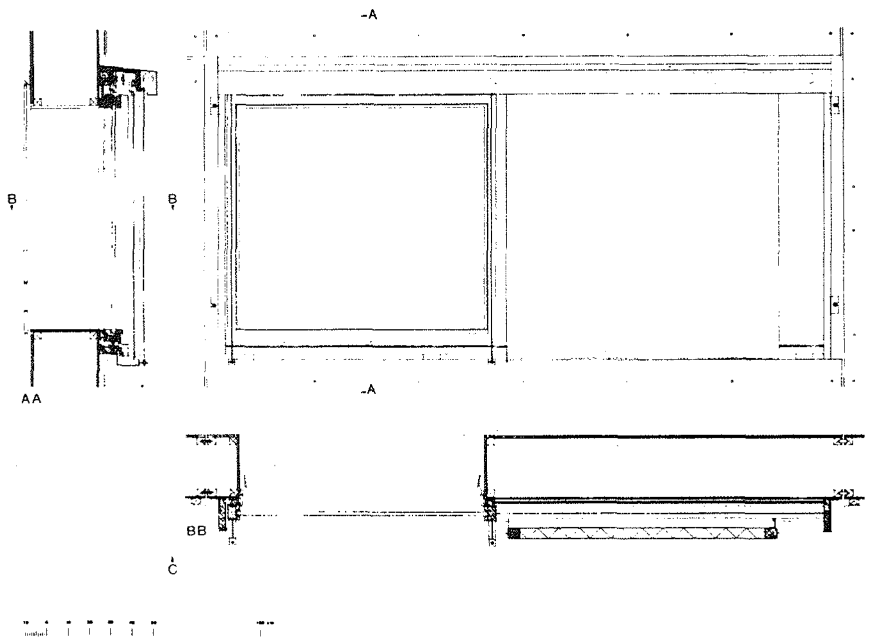
From the continuous registration of the indoor temperature and the outdoor temperature and from periodical measurements of the heat loss by transmission and heat loss by ventilation, a specified heat balance is calculated for the period October 1976 till June 1977:

Heat loss by transmission	10000 kWh	
Heat loss by ventilation	4000 kWh	
		14000 kWh

Heat supply from persons	1600 kWh	
Heat supply from electric lighting etc.	4700 kWh	
Solar heat gain through windows	1900 kWh	
Supply from the solar energy system	2500 kWh	
		10700 kWh
Necessary auxiliary electric heat supply		3300 kWh

Efficiency of mobile insulation.

The U-value for windows with shutters was originally calculated to 0.4 $W/m^2 \cdot {}^{o}C$.



Vindue. Opstalt, vandret og lodret snit.

Window with shutter. Front view, horizontal and vertical section

Figure 2.

The U-value for the outside windows with shutters has been measured to 0.9 $W/m^2 \cdot {}^oC$. This difference is due to thermal bridges in the construction and to ventilation in the space between windows and shutters because of an insufficient tightness.

The U-value for the windows and shutters facing the atrium has been measured to 0.5 $W/m^2 \cdot {}^oC$. In this case the shutters are closed with magnetic locks, and therefore the air tightness is very high, and the thermal bridges are reduced essentially.

Energy consumption for hot water supply.

In the calculations of the heat balance, it was assumed that the amount of hot water supply was 350 liter per day at 43° C corresponding to 420 kWh per month.

It was furthermore assumed that the heat recovery equipment in the waste water system had an efficiency of 50%. Therefore the amount of energy for hot water supply should not exceed 210 kWh per month.

Due to problems with the filter in the heat recovery equipment it has not been in operation during the past winter period, and the hot water supply was assumed to 420 kWh per month, totally 4200 kWh for the 10-months period, the house has been occupied.

The actual amount of hot water supply in this period has been measured to 3000 kWh, corresponding to 220 liter per day at 53°C (or 290 liter per day at 43° C).

In the beginning of the period, October 1976, it was clear, that the heat requirement for space heating would be greater than calculated, and therefore the solar energy system would not be able both to supply the space heating requirement totally and the hot water supply totally. Therefore it was decided to cover the hot water supply totally with electricity during this winter period. From May 1977 the solar energy system again has covered the hot water supply totally.

The solar energy system.

The solar energy system consists of a flat-plate solar collector, a heat storage tank and a heat distribution system.

The solar energy system is dimensioned on the basis of the following criteria:

1. For architectural reasons, it was decided that the area of the flat-plate collector should not exceed 42 m^2 (12 m long and 3.5 m high), and that the collector should be vertical.
2. Because the system is used also for hot water supply, the temperature in the storage tank must not be lower than 43° C.
3. With the area of the collector fixed at 42 m^2, the accumulator should be dimensioned in such a way that the solar energy system is able to cover the heat requirement for the house on

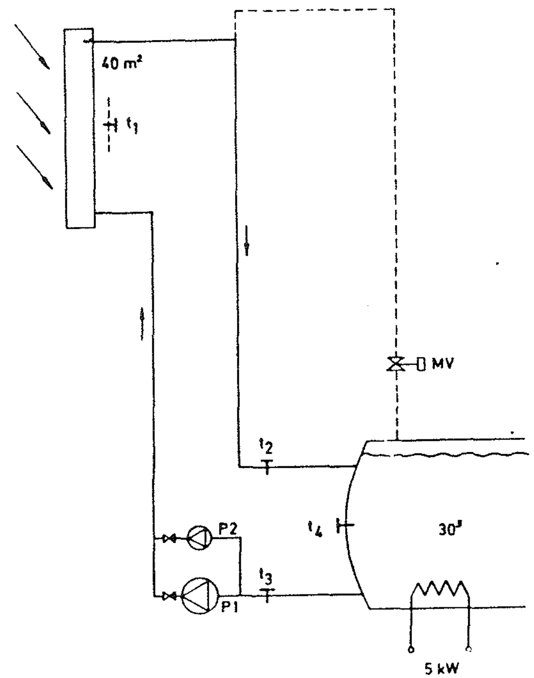


Figure 3

the basis of the "Reference Year" and the hot water supply.

The solar collector.

The collector is of the flat-plate type. The absorber is a roll-bond steel radiator painted with ordinary carbon black paint, insulated on the back with 25 cm of mineral wool. The front of the collector is standard hermetically sealed, double pains framed in steel bars, and sealed with a mastic.

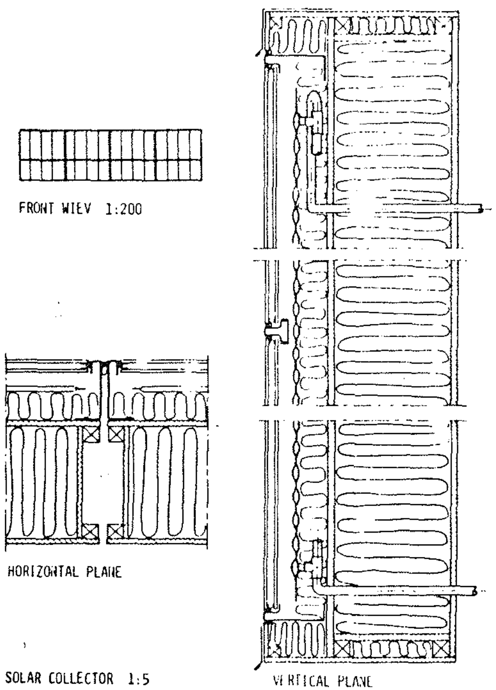


Figure 4

Under the worst conditions which means no water circulating through the absorber plates and clear sunshine almost perpendicular to the collector, the temperatures in the collector are very high.

On a sunny day in February 1975 these conditions occurred. The temperature was measured to 140^{o} C on the absorber, 120^{o} C on the inner glass and 60^{o} C on the outer glass. Due to this temperature difference on 60^{o} C between the inner and outer glass the inner glass was broken in almost 25% of the collector area.

Therefore it is very important, that the cover glass is mounted in such a way that it is possible for the glass to move under the varying temperatures. Maybe it will be a better solution to use 2 single layers of glass instead of a hermetically sealed double pane.

The accumulator.

The accumulator is designed as a cylindrical steel tank, 2.5 m in diameter and 6.5 m long with a volume of 30 m^3. The tank is insulated with 60 cm of mineral wool. The ground water level is far below the tank bottom. To prevent rain water from penetrating the insulation, an earth-covered roof is built on the top of the insulation separated by a mechanically ventilated air space.

A 400 litres storage tank for the domestic hot water is built into the accumulator.

The heat conductivity coefficient for the mineral wool is 0.044 W/m$\cdot^{o}$C, and it is assumed that in the calculations of the heat loss the temperature of the surroundings (the ground) is constantly 15^{o} C.

The heat loss is then calculated to 5.8(t_4-15) Watt, where t_4 is the actual temperature in the accumulator.

In the first year of operation, however, the heat loss has been about twice as big as calculated. The cover of the 400 litres storage tank has been leaking due to temperature changes, and the surrounding insulation got wet. For this reason we must warn against bringing a similar system under pressure before the highest temperatures have reached, and the bolts of the cover have been tightened once more.

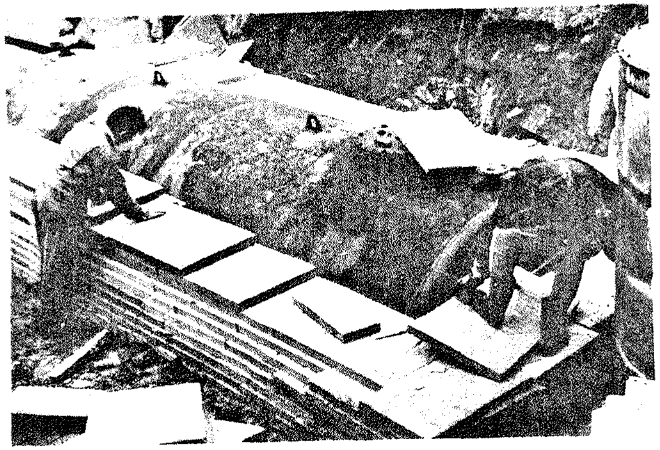


Figure 5. The accumulator is insulated with 60 cm of mineral wool.

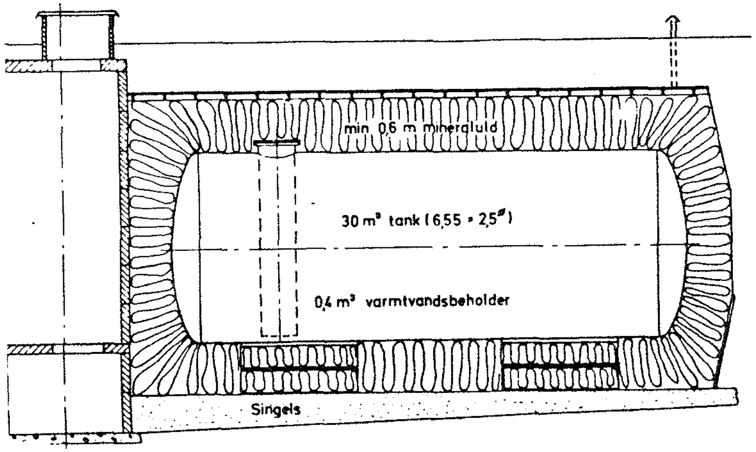


Figure 6. Sketch of the accumulator buried just outside the house.

Utilized solar energy.

The solar heat gain during the period August 1, 1976 till July 31, 1977 has only been about 65% of the solar heat gain during the corresponding period in the Reference Year.

The total solar heat gain on the vertical surface facing south (the effective area is 38 m^2) has in the period been 26980 kWh (710 kWh/m^2) compared to 40800 kWh (1070 kwH/m^2) in the Reference Year.

The utilized solar energy in this period is measured to 5600 kWh (21% of the solar heat gain).

For the corresponding period of the Reference Year the utilized solar energy is calculated to 7300 kWh (18% of the solar heat gain).

The efficiency of the solar energy system is measured about 3% higher than calculated in the Reference Year. It corresponds with the fact that the temperature in the storage tank has been lower in the measuring period than in the Reference Year.

The energy balance of the solar heating system.

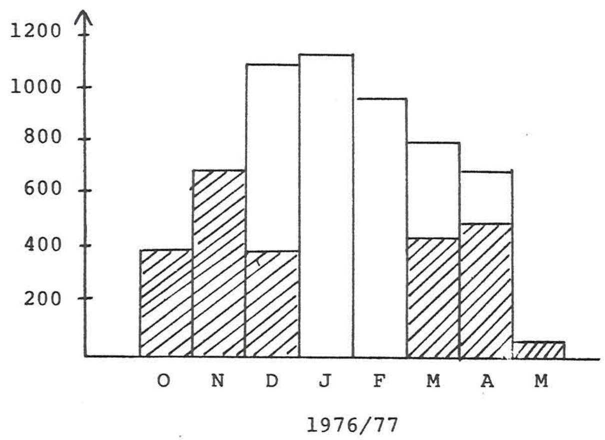
The originally energy balance calculated for the period August 1 till July 31 in the Reference Year:

The amount of energy in the storage tank (calculated from 0^o C) per August 1		2600 kWh (74^o C)
Utilized solar energy August-June		7300 kWh
		9900 kWh
For space heating	2300 kWh	
For domestic hot water	2300 kWh	
Heat loss from the storage tank	2700 kWh	
		7300 kWh
The amount of energy in the storage tank per July el in the Reference Year		2600 kWh (74^o C)

The <u>measured</u> energy balance for the period August 1, 1976 till July 31, 1977:

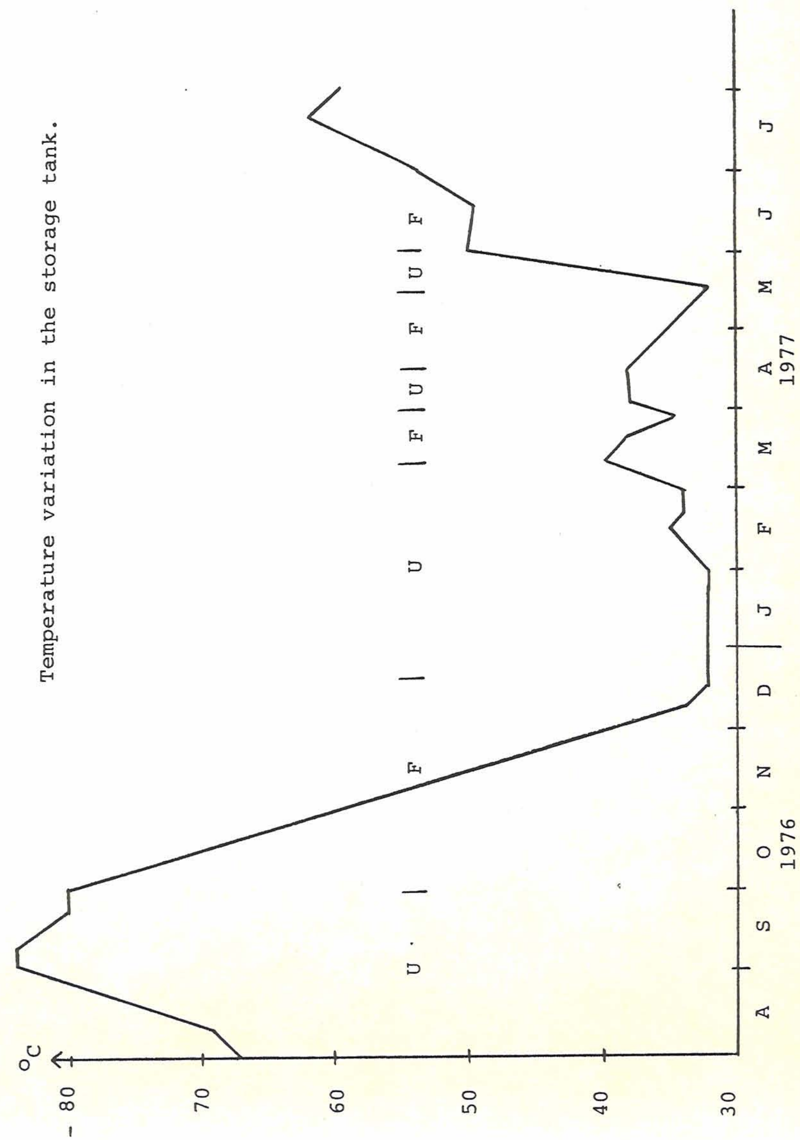
The amount of energy in the storage tank (calculated from 0° C) per August 1, 1976		2340 kWh (67° C)
Utilized solar energy in this period		5600 kWh
		7940 kWh
For space heating	2500 kWh	
For domestic hot water	300 kWh	
Heat loss from the storage tank	3000 kWh	
		5800 kWh
The amount of energy in the storage tank per July 31, 1977		2140 kWh (61° C)

The degree of covering for the solar heating system.



Heat requirement for space heating	5860 kWh
covered by solar energy	2500 kWh (43%)

Temperature variation in the storage tank.



F: Periods with heat consumption from the storage tank.
U: Periods without heat consumption from the storage tank.

Reactions from the occupants.

During the summer period, the family in the house has used the atrium as a livingroom, which means that the useful livingspace is increased with 50%.
The windows facing south are relatively small, and they are provided with a sun shading device, which means that there have not been problems with high indoor temperatures on sunny days.

It was very interesting to see if the family would feel comfortable in this high-insulated, very tight house during the winter period.

However the family has been very satisfied with the indoor climate. The ventilation system has supplied the house with a sufficient amount of fresh air, and it has not at any moment been necessary opening the windows to ventilate the room.

The only thing which is different by living in the Zero Energy House is to remember closing and opening the insulating shutters.

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