THERMAL INSULATION LABORATORY
TECHNICAL UNIVERSITY OF DENMARK

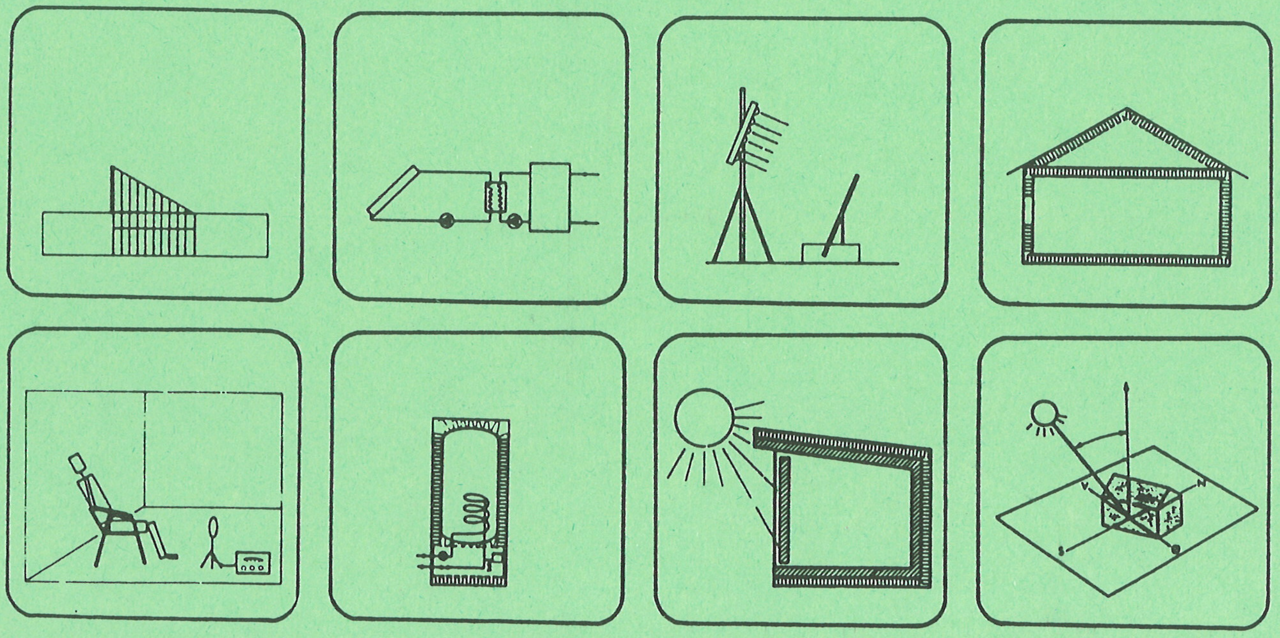
A SOLAR WATER AND SPACE HEATING SYSTEM FOR NORTHERN EUROPE

P. E. KRISTENSEN

SEPTEMBER 1983

REPORT NO. 141

PERFORMANCE MONITORING GROUP PMG - COMMISSION OF THE EUROPEAN COMMUNITIES



SOLAR SYSTEM CASE STUDY

A SOLAR WATER AND SPACE HEATING SYSTEM FOR NORTHERN EUROPE

SEPTEMBER 1983

P.E. KRISTENSEN
THERMAL INSULATION LABORATORY
TECHNICAL UNIVERSITY OF DENMARK

PERFORMANCE MONITORING GROUP
COMMISSION OF THE EUROPEAN COMMUNITIES

PREFACE

The CEC Performance Monitoring Group is one out of six concerted actions under project A of the CEC Solar Energy Recearch and Development Programme.

The Performance Monitoring Group consists of representatives from eight of the ten member countries of the CEC: United Kingdom, Belgium, Germany, Ireland, Italy, France, the Netherlands and Denmark. The members of the group are:

PROJECT CO-ORDINATION - UK

Richard Ferraro - Architect
Ramiro Godoy - Engineer
Energy Conscious Design
11-15 Emerald Street
London WC1N 3QL

GERMANY

Ulrich Luboschik
Engineer
IST Energietechnik GmbH
Kandern Wollbach

BELGIUM

Arnold Debosscher
Mechanical &
Electronics Engineer
Katholieke Universiteit
Leuven

IRELAND

J Owen Lewis
Architect &
Building Services Engineer
School of Architecture
University College Dublin

DENMARK

Poul Kristensen
Engineer and Building
Scientist
Thermal Insulation Laboratory
Technical University of
Denmark, Lyngby

ITALY

F Cecchi Paone
Engineer
Fidimi Consulting Spa
Rome

FRANCE

Gerard Kuhn
Professor and Engineer
CNRS - CRTBT
Grenoble

NETHERLANDS

Cees den Ouden - Engineer
Dick Brethouwer - Engineer
Institute of Applied Physics
TNO-TH Delft

The persons responsible for the project at the Commission are:

T. C. Steemers and W. Palz
Directorate General XII, Rue de la Loi 200, B-1049 Brussels

Scientific Adviser to the Commission: Cees den Ouden

From the start of the Performance Monitoring Group in 1979 and until 1982, the prime objective of the work was to collect and analyse data from solar houses around Europe. One conclusion drawn on this work was that all the solar heating systems seen so far were oversized, complicated and had poor economy. In the group it was felt that a much better performance to cost ratio could be achieved through careful design. Therefore a series of Performance Optimisation Studies were undertaken by the group in 1982/83.

The Performance Optimisation Studies were carried out by three groups of experts, each group being responsible for the design of a solar DHW system and a combined water and space heating system. In this report the work of one of these groups, the Northern European design group, is presented.

The other groups were the Northern/Central European design group based at TNO/TPO in Delft and the Southern European Design Group based at the University of Grenoble. Additionally an investigative study of a passive solar design for Central European climate was carried out by the UK representative of the group.

All the work carried out by the Performance Monitoring Group during the period January 1982 to October 1983 is reported in the following reports from the Commission of the European Communities:

1. Solar Heating - Performance and cost improvements by design.

2. Solar Heating - Performance of recent systems.

3. Solar Heating - Performance Monitoring 82/83
   - Executive summary and recommendations.

The three reports are edited by R. Ferraro and R. Godoy, and they were all published by the CEC in November 1983.

This report together with the parallel report on the solar water heater represent the work which was done by the design group based at the Thermal Insulation Laboratory.

Poul E. Kristensen

CONTENTS

List of figures

5.1 INTRODUCTION

This report outlines the findings of a system optimisation study for a combined solar heating system for domestic hot water and space heating. The study was carried out under given constraints such as climate and local HVAC regulations.

The prime objective was to develoe a solar heating system with a maximum output per invested ECU. Secondary objectives were to produce:

1. a system that would operate without any interference on the user´s part,

2. a high degree of reliability; since owing to the back-up heating system it would not always be possible to determine decreases in performance.

The work was carried out in 3 different stages. The first stage, referred to as "sketch design" represents a primary attempt based on conclusions drawn from previous experience.

The second or intermediate stage known as "initial or fist design" is discussed in sections 5.9 - 5.11 towards the end of the report.

The final design is presented in sections 5.2 - 5.8.

The system optimisation work was carried out by the following group of specialists:

Svend E. Mikkelsen, TIL (Modelling)

Poul E. Kristensen, TIL (System design)

Per Alling, Dansk Solvarme (manufacturer of solar systems, architect)

Torben V. Esbensen, Consulting engineer (Engineering Aspects)

Thanks are due to the following for assistance and encouragement:

- Roslev Houses, Skive who provided one of their standard model houses for the case study.

- Finn Straboe, architect, for invaluable advice on overcoming architectural problems and for illustrations of same. Finn Straboe is now working at the Technological Institute.

- Colleagues at the Thermal Insulation Laboratory, especially Ole Balslev Olesen for system modelling and Lars Olsen for modelling the heating load.

- Birthe Friis who typed the manuscript.

5.2 HOUSE DESCRIPTION

5.2.1 Introduction

This section is devoted to a discussion of the case study house chosen for the study. A background for selection of the actual house i given followed by a detailed description of constructions and heating load. Finally, the integration of the solar collector and the storage tank is discussed.

The Danish housing market offers a large choice as to both style and size of dwelling. The actual house used in the case study was selected from among the standard low-to-medium cost range of housing currently available.

5.2.2 Analysis of local housing parameters

At present (beginning of 1983) it is difficult to predict how the market for new dwellings is going to develop in the near future.

The number of houses being built has dropped significantly since 1980, and most of the new housing reflects the constraints of the economic situation and is largely constructed with the aid of public subsidies.

New housing before 1980

The economic crisis which followed the "oil crisis" in 1973 did not really influence Danish housing before the end of the seventies. The dwellings being built in the seventies were to a large extent similar to those being built in the sixties. Most of them were detached single-family houses being built both by individuals and by standard-housing contractors. The gross floor area increased from 100 m^2 to approximately 150 m^2 throughout the sixties and until 1973/74. After that date a decrease in size to between 120 - 140 m^2 is noted.

The total stock of dwellings as of January 1st 1981 was:

	units	%
a. detached single-family houses	1,058,000	49
b. non-detached or semi-detached houses	164,000	8
c. dwellings in multi-family buildings	893,000	41
d. others	46,000	2
	2,161,000	100

The gross areas per dwelling were 130 m^2 for detached houses and 97 m^2 for non-detached or semi-detached houses.

Apartments have an average area of 74 m^2.

Housing in 1980 and 1981

As previously mentioned, the situation regarding new housing at the beginning of the eighties was greatly influenced by the economic set-back following the oil-crisis. However, this did not really affect the daily life of the Danes until the end of the seventies.

Throughout the sixties and at the beginning of the seventies around 40,000 dwellings per annum were being built, the major part of those being detached houses. In 1980 a total of 29,000 dwellings were completed. The figure for 1981 is only 21,000, and the figure for 1982 is expected to be even lower. The statistics for the two years are as follows:

	detached	non-detached or semi-detached	apartments
completed in 1980	15.207	7.297	6.783
approved* in 1980	9.036	7.461	5.457
completed in 1981	6.941	7.667	5.964
approved* in 1981	4.347	8.531	5.484

* i.e. Approved by the local municipality so that the dwelling may be built.

It can be seen from the chart that the number of non-detached single family dwellings is quite stable at 7-8000 per annum, whereas a dramatic decrease in the number of detatched houses being built is shown over the two years.

The gross floor area also fell significantly in the same period, going from 154 m^2 per single family house (detached and non-detached) in 1980 to 139 m^2 in 1981. Houses under construction at the end of 1981 had a gross floor area of 129 m^2 and houses approved in 1981, 124 m^2. These figures are representative of house size per single family home with regrettably no further breakdown into separate detached and non-detached categories.

The floor area for apartments is un altered with an average of 80 m^2 per apt. over the two years.

Danish housing after 1983

Danish housing after 1983 will be influenced by at least two major factors. These are:

a. A growing optimism is felt as regards the prospects for economic stability. This will certainly affect the housing sector, especially since the rate of interest to be paid on loans for a new house has dropped from 22% at the end of 1982 to 15% in the spring 1983.

b. During the years of increasing pessimism as regards the economic prospects (1979-1982), many potential buyers of new houses hesitated because of the high rate of interest and the economic instability. Many of these people can be expected to realize their wish for a new house in the next couple of years.

The market for non-detached and semi-detached houses (and multi-family dwellings) is at present dominated by buildings receiving some kind of public financial support. This market may increase a little but the tendency is that the expected increase in new dwellings being built will primarily occur in the privately financed sector (as did the decrease at the end of the seventies).

House types and sizes

Almost all of the houses being built in the private sector are detached or semi-detached (terrace houses or cluster houses). The houses being built with public support vary from small detached houses to clustered houses and terraced houses. No one type seem to be more popular than the others.

Houses for rent

In 1983 a total of around 9000 dwellings, being publicly financed and for rent, will be built. These dwellings will primarily be built as multi-storey buildings, but some may also be characterised as low-density buildings.

Private houses with public support

The quota in 1983 for private co-operative associations receiving loans of low interest is 3,500 dwellings. This quota is expected to be fully exploited. An inquiry between contractors and architects working in this field shows that the house sizes vary between 60 and 130 m^2, typically between 70-110 m^2 with a medium around 90 m^2. The maximum area allowed is 95 m^2 (medium) with an absolute maximum of 130 m^2. The total expenses allowed vary from 5,600 dcrs/m^2 to 6,100 dcrs/m^2 all inclusive depending on location in Denmark. Actual expenses are normally very close to the limit allowed.

The inquiry did not give a very clear picture as to which types of houses one could expect in this sector (co-operative associations). However, it looks as though there are two main categories. The first category includes detached houses and cluster houses. The second category comprises terraced houses where two adjacent houses share an exterior wall. Both one-storey houses and 1 1/2 storey houses (one-storey houses with occupied roof) are very popular. The slope of the roof in the former is 13-25^o and in the latter 40-55^o from horizontal.

Private houses

Most of the houses being built in this sector are and will be detached. Both single-storey and 1 1/2 storey houses are very popular. The gross floor area can be expected to range from 80 m^2 to 130 m^2 (not including luxury houses). The average house is expected to have a gross floor area of 90-110 m^2.

The total cost for a house in this sector will be very close to the maximum cost allowed for a house receiving public support, i.e. 680 - 810 ECUS per m^2 gross area (22% VAT exclusive). The total investment for a 100 m^2 house will then be 75,000 ECUS with all expenses and site purchase included. The gross expenses per annum for such a loan will be around 11,200 ECUS (basis 14.5% interest rate). The net expenses when tax deduction of the interest is taken into account is around 5,000 ECUS per year.

5.2.3 Case Study House: description

The house chosen for the case study is a typical single-storey standard detached house. The total living area within the exterior walls is 99 m^2. The gross floor area is 116 m^2.

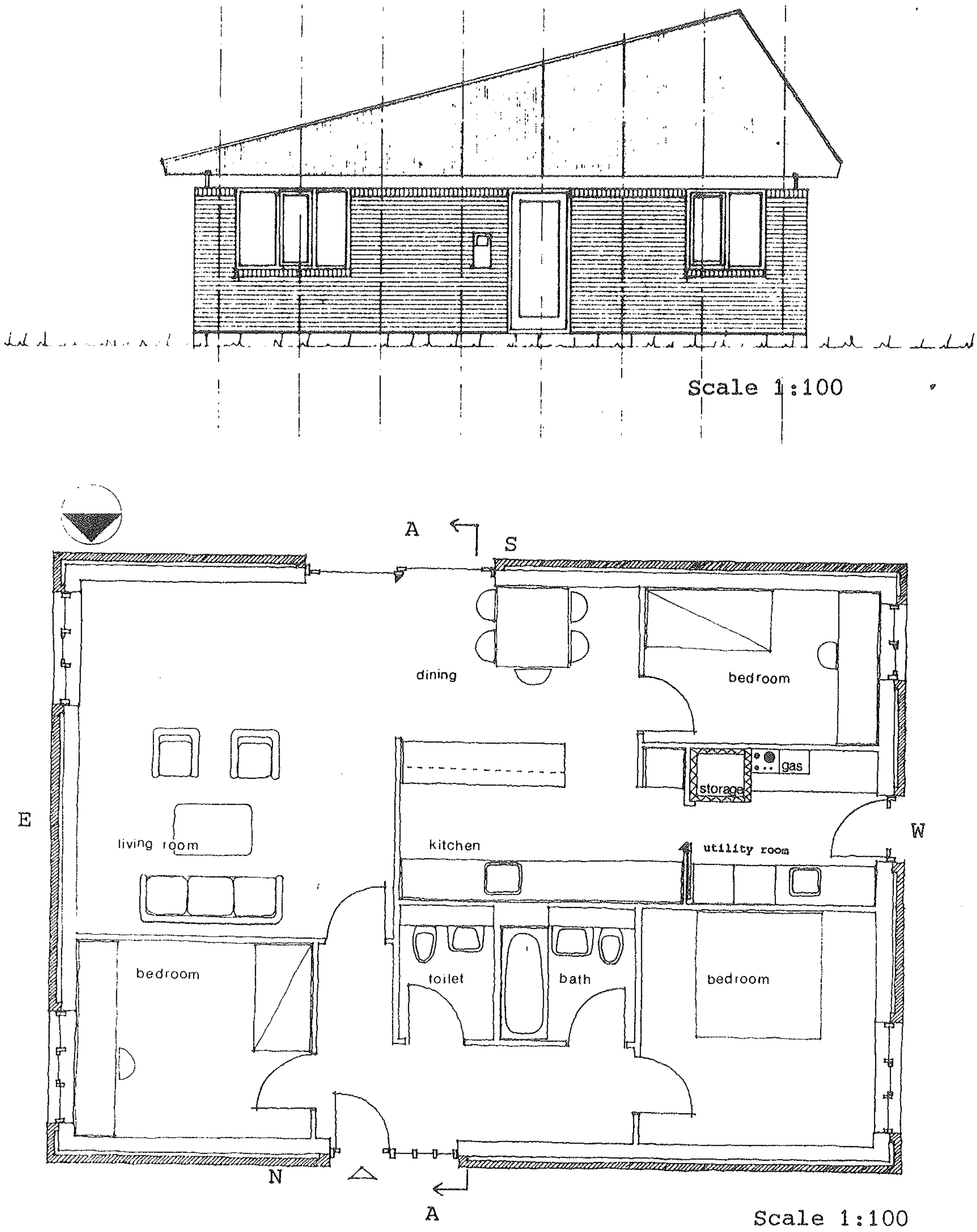


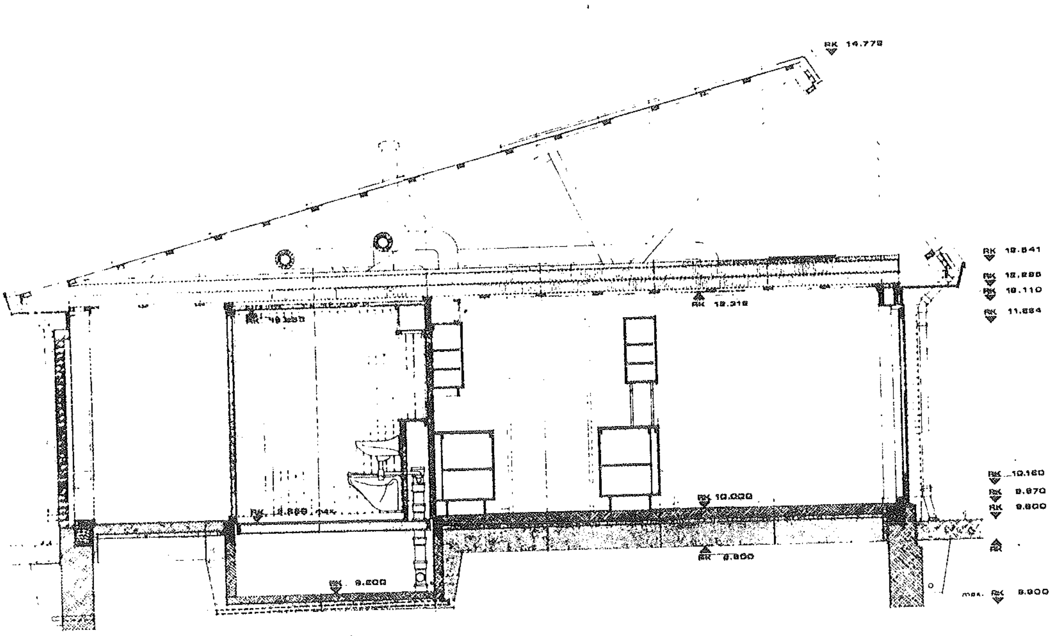
Fig. 5.1 Case study house

5.2.4 House construction, insulation and loads

Construction and insulation

The total window area is 20 m^2 with 30% facing south, 28% east, 21% west and 21% facing north. All the windows have three pane glazing with heavy gas in the cavities.

The exterior walls have 110 mm of brick, a 61 mm cavity, 200 mm of mineral wool and 12 mm of chip board. The roof is insulated with 300 mm of mineral wool and the floor with 50 mm of mineral wool and 250 mm of clay clinkers.



Scale 1:80

Fig. 5.2 Cross-section A-A through case study house, see fig. 5.1.

The U-values are:

exterior walls	: 0.20 W/m^2 ^oC
roof	: 0.14 -
floor	: 0.22 -
windows	: 1.85 - (2.20 for glazing and casement)

The loft is ventilated (naturally) with ambient air.

The transmission heat losses of the actual case study house are given in fig. 5.3. Also shown in this figure are the requirements of the current Danish Building REgulations (BR82), see also appendix 5.1.

	Area	Temperature difference	Standard regulation	Building house	Roslev house	
	A	Δt	k_{max}	$k_{max} \cdot \Delta t \cdot A$	k	$k \cdot \Delta t \cdot A$
	m^2	K	W/m^2K	W	W/m^2K	W
Floor over ventilated cellar (krybekælder)	6,8	26	0,30	53	0,32	56
Floor (external part)	36,5	33	0,30	361	0,25	301
Floor (internal part)	56,1	13	0,30	219	0,22	160
Roof	99,4	38	0,20	755	0,14	529
External walls	84/86,4	33	0,40	1109	0,20	570
Windows	17,4/19,8	33	2,80	1608	2,20	1437
Total				4105		3053

Fig. 5.3 Transmission heat losses through external surfaces

It can be seen that the transmission heat loss is 3053 W at $t_i = 21^{o}C$ and $t_a = -12^{o}C$. This figure is 26% lower than the maximum heat loss accepted. It is becoming quite usual for dwellings to be better insulated than is required by law.

The house is thermally light with thermal masses of 9 mm gypsum in the loft, 12 mm of chip board on the walls and 100 mm of concrete covered by carpets on the floor.

The total heat loss coefficient (ventilation with heat recuperation) is 125 WK^{-1}. This house type was developed by Roslev Huse, Skive, for the Skive 79 low energy housing exhibition. The house is heated via a radiator heating system or via electric panels. The house may optionally be supplied with a solar system for space heating and DHW.

<u>Load</u>

The performance of the house has been modelled using the Danish BA4-programme (reference 5.3). The house is modelled as one room, and the time step is 1/2 hour. The model takes internal heat gains as well as passive solar gains into account. The annual gross figures for these are:

Person and electrical applicances: 5,180 kWh

Solar radiation through windows: 5,590 -

Weather data: Danish Test Reference Year, ref. 5.4

The required internal temperature: $21^{o}C$

Month	Heating load kWh	Part of total load %
Jan.	1494	20
Febr.	1251	17
March	1005	14
April	499	7
May	225	3
June	31	0
July	25	0
Aug.	34	0
Sept.	122	2
Oct.	502	7
Nov.	907	12
Dec.	1267	17
year	7362	100

Fig. 5.4 Monthly heating load

The total heating load to be covered by the active heating system is 7360 kWh. Out of this 99% occurs in "the heating season" September - May inclusive.

5.2.5 Main influences on house design caused by addition of the solar system

The house design is influenced in two ways by the solar heating system:

1. The roof construction is modified in order to allow a collector tilt angle of 56^{o}, which is close to being optimal (see section 5.6.3); and

2. Space has to be allowed in the house for the heat storage tank.

Modifying the roof construction to make the roof asymmetrical will not increase the cost since the rafter sections (see fig. 5.2) can be manufactured in the normal way with no additional use of materials.

The only modification to the standard floor plan is in the utility room where the storage tank is situated. The door between the utility room and the kitchen has been changed to a sliding door in order to provide better access between the two rooms.

The windows facing south might be modified re. size and type in order to complement the solar collectors in the roof construction. This is discussed in section 5.9.

5.2.6 Integration of the solar collector.

The solar collector consists of partly prefabricated units. The collector also functions as a roof covering.

The details re. collector construction are discussed in section 5.5.2. The integration of the solar collector is also discussed in that section, because the collector is finally assembled on-site.

5.2.7 Integration of the heat storage tank

The heat storage tank is discussed in detail in section 5.5.4. The tank is box-shaped, and is insulated on site. It takes up 0.75 m^2 of floor space. Two of its sides are against walls and the two other sides are covered with chip board, see figure 5.1.

5.3 SITE PLANNING

5.3.1 Introduction

An area of land for construction may be divided into either small sites for individual contractors build detached single family houses on a one-off basis, or very large parcels destined to be developed as built-up areas comprising detached, terraced, and appartment block housing. The legal requirements regarding site planning and housing density allow for more flexibility in the large parcels than the small sites.

Detached single-family houses

The minimum site area allowed is generally 700 m^2. A few municipalities around Copenhagen do not allow such small sites, and the minimum is then between 1000-1200 m^2.

The maximum size allowed for a house is 25% of the site area. The size of the house is then taken as the gross floor area including the exterior walls. Special rules apply for the calculation of the floor area of a habitable attic storey, see ref. 5.6.

Houses may not have more than two storeys plus basement. Two-storey detached houses are seldom seen however. Both one storey houses and 1 1/2 storey houses (one storey house with habitable attic storey) are very popular. Basements are not common in new housing.

The maximum ridge height allowed is 8.5 m above surrounding ground level. There are special regulations governing the erection of high buildings too near an adjacent boundary (see 3.1.3 in ref. 5.6) and normally no house may be built closer than 2.5 m to the neighouring plot. Small secondary buildings however such as garages and carports may be constructed nearer to adjacent boundary and it is common practice to do so.

A typical housing density is 10 dwellings per hectar, when including roads, shared parcs, etc.

Semi-detached houses and terraced houses

This category includes cluster houses and terraced houses. These dwellings are built on a site by one contractor. The geometry and the layout of the built-up area is fixed from the beginning. This means that the requirements regarding privacy, fire regulations, etc, may be fulfilled even if the requirements stated re. single-family houses are not met. Sites smaller than 700 m^2 may be allowed, and the houses may be built together as terraced houses.

The plot area for each dwelling may be as small as 250 m^2, but the average size is more likely to be 400-600 m^2. These areas do not include local roads and areas shared between all the dwellings (lawns, playgrounds, etc.).

If these areas are included, the plot area per dwelling rises to 400-1200 m^2 with a typical range of 600-1000 m^2. The density of dwellings corresponds to 10-20 dwellings per hectar.

The requirements re. height and number of storeys are the same as for detached houses, i.e. maximum height 8.5 m and not more than two storeys, basement excluded.

5.3.2 Density and overshading

The basic floor plan of the house was shown in fig. 5.1. This layout presupposes access to the house from the north side. In order to achieve more flexibility when planning a site layout, the floor plan was modified to allow access from the south side via the main entrance door in the western facade. Such a layout is shown in fig. 5.5. The window arrangement is also changed so that one gable does not have any windows. Furthermore, the window module to the south is adapted to the glazing module of the solar collector (1 m). The storage tank arrangement is now at the north side of the utility room.

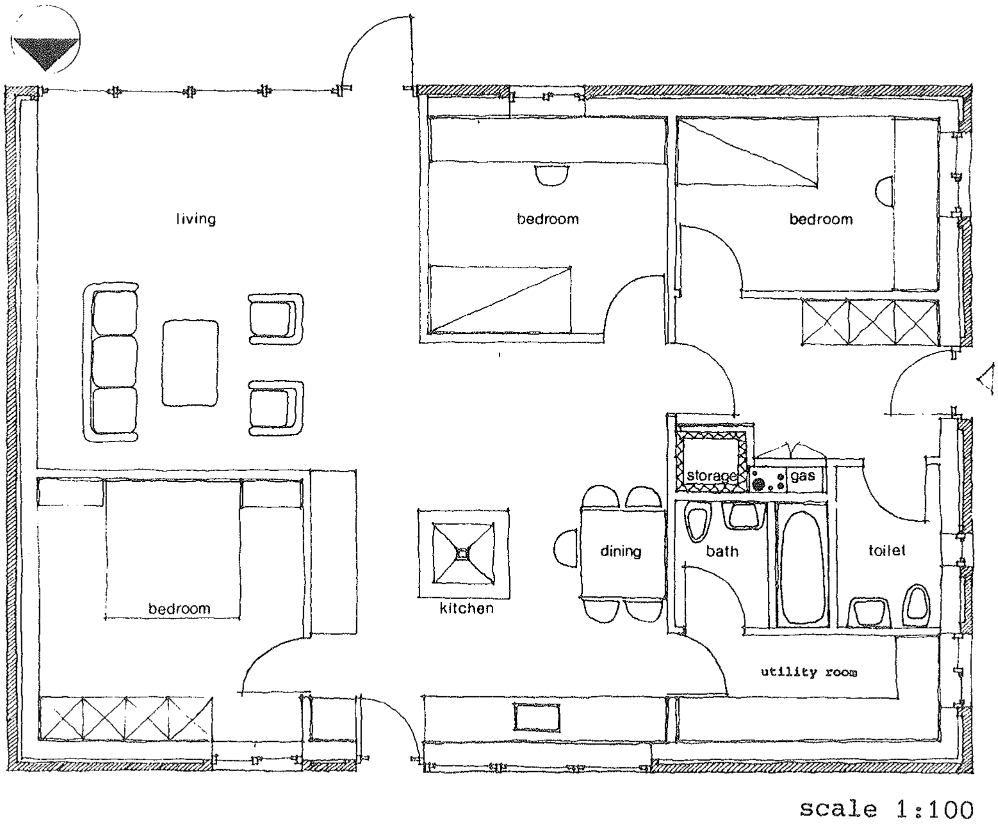


Fig. 5.5 Optional floor plan of case study house

Density

A possible site layout is shown in fig. 5.6. The layout consists of 16 houses situated between two main roads. The houses at the right half part of the layout are houses as shown in fig. 5.5. The others are handed versions. Behind the buildings, partly shared carports are shown.

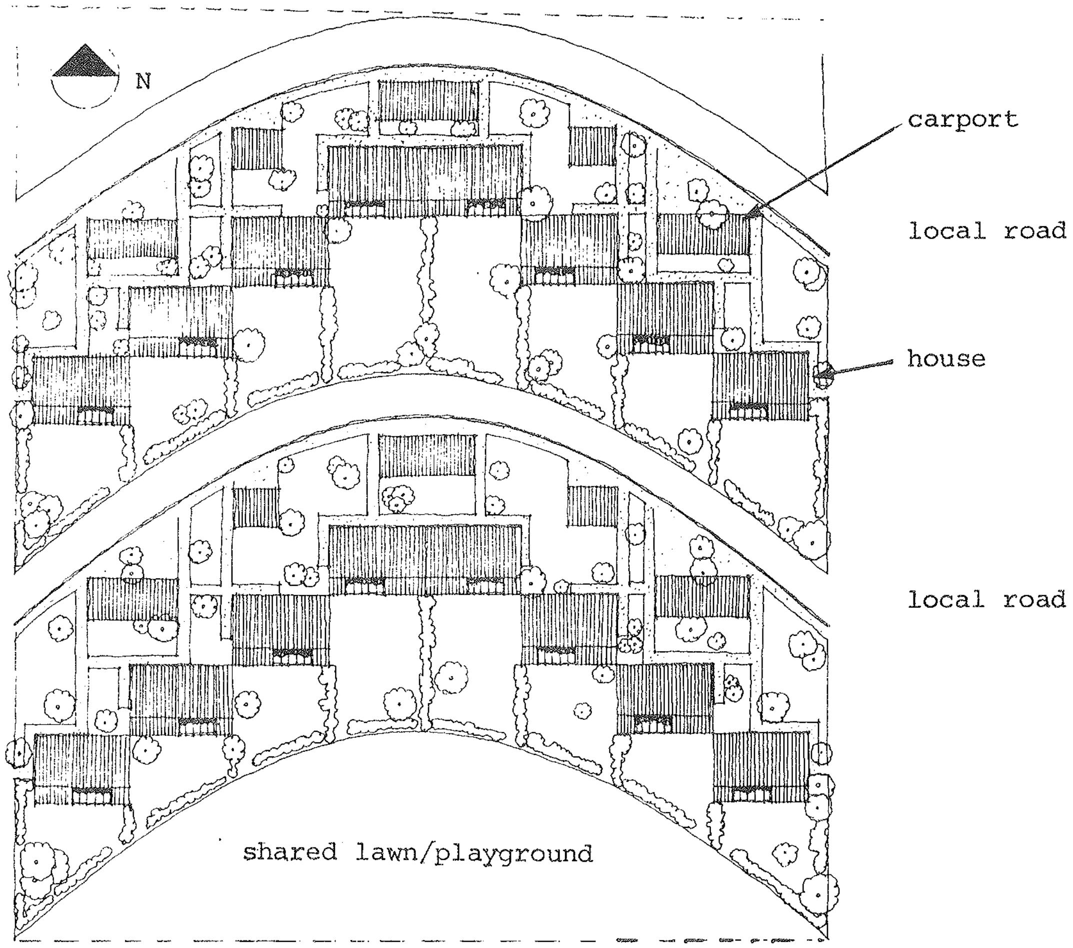


Fig. 5.6 Site layout

The gross site area within the rectangle shown is 13,000 m^2. This corresponds to 810 m^2/house, or 12 houses per hectare. If the "white" areas are excluded, the gross site area, including local roads, is reduced to 10,000 m^2 or 625 m^2/house or 16 houses per hectare. If local roads are excluded, the site area is reduced to 8,500 m^2 or 530 m^2/house.

Overshading

In fig. 5.7 the position of the sun at 10.oo and 14.oo (sun time) is shown for three days of the year: December 21, March 21 and June 21. It is seen that overshading from one house to another does not occur. The slope of the ground and surrounding trees will be the main factors which may affect overshading of windows and solar collector.

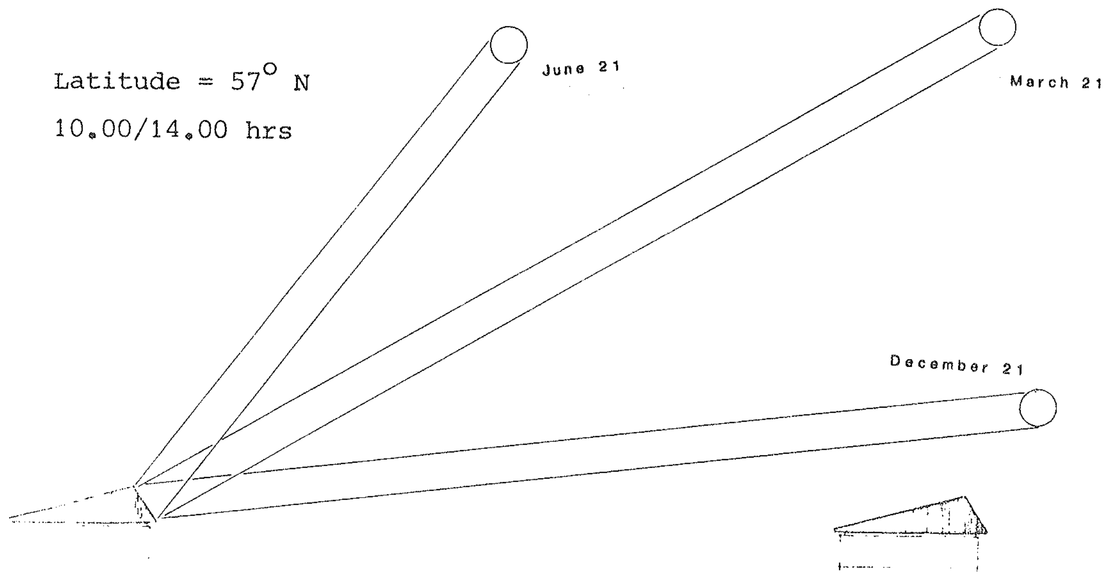


Fig. 5.7 Sun angles at 10.00 and 14.00 hrs.

5.3.3 Orientation and access

Basically, the house layout shown in fig. 5.5 can allow access from the southern, western, northern and eastern side (inverted version). Access from the south side will put restrictions on the site layout. An arrangement with semi-detached houses at intervals of 5-6 meters is possible.

5.3.4 Privacy

The site layout shown in fig. 5.6 maintains good privacy between the houses. The gardens face south and are bound by the western or eastern facade of the neighbouring house (no windows) and hedges.

The entrance area of the two adjacent houses presents some problems re. privacy. The kitchen entrance door of one house is very close to the window of a neighbouring bedroom. This might be solved by moving the bedroom window to the south side of the house. Another problem concerns the window of the bedroom to the north, which is close to the main entrance of the neighbouring house. This could be solved by a wooden fence 3 m long and 1.8 m high between the two houses.

5.4 SYSTEM DESCRIPTION

5.4.1 Introduction

The system design concept developed in the case study is primarily based on experience gained from earlier experiments with full scale systems. Such systems have been tested both at the full scale Solar Pilot Test Facility (SPTF), and in private dwellings. These experiments gave invaluable information as to system performance and system reliability.

5.4.1 Introduction

The main problems with earlier systems for combined space heating and water heating systems were found to be:

1. They were oversized and complicated resulting in poor cost-effectiveness.

2. The performance was decreased due to poor collectors and due to heat losses from the heat storage tank and the piping.

These problems are discussed in section 2.10, where a description of the first design of this case study is included.

The major improvements of this first design over previous designs are:

1. Solar energy for space heating is distributed via a separate radiator, which means that solar energy can be used down to storage temperatures of 20°C.

2. The DHW tank is integrated into the space heating store.

3. Heat losses from components in the system are decreased by installing them in an insulated cabinet.

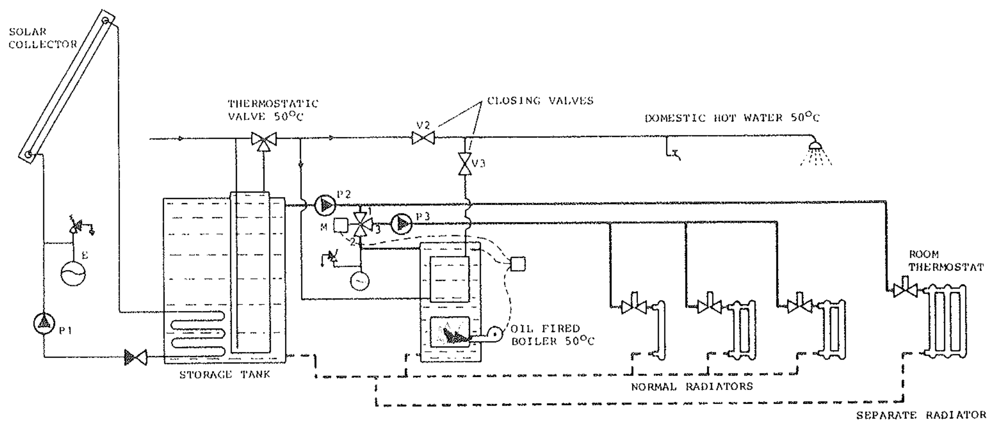


Fig. 5.8 System diagram, 1st design

The main feature which requires further improvement is the control strategy of the auxiliary boiler. The user has to watch the storage temperature very carefully in order to switch off the boiler for as long as possible.

5.4.2 Final design

The final design is in many aspects similar to the first design. The major difference is that postheating of DHW now takes place in the solar preheating tank, see fig. 5.9, as opposed to the previous design where there is a separate DHW auxiliary tank.

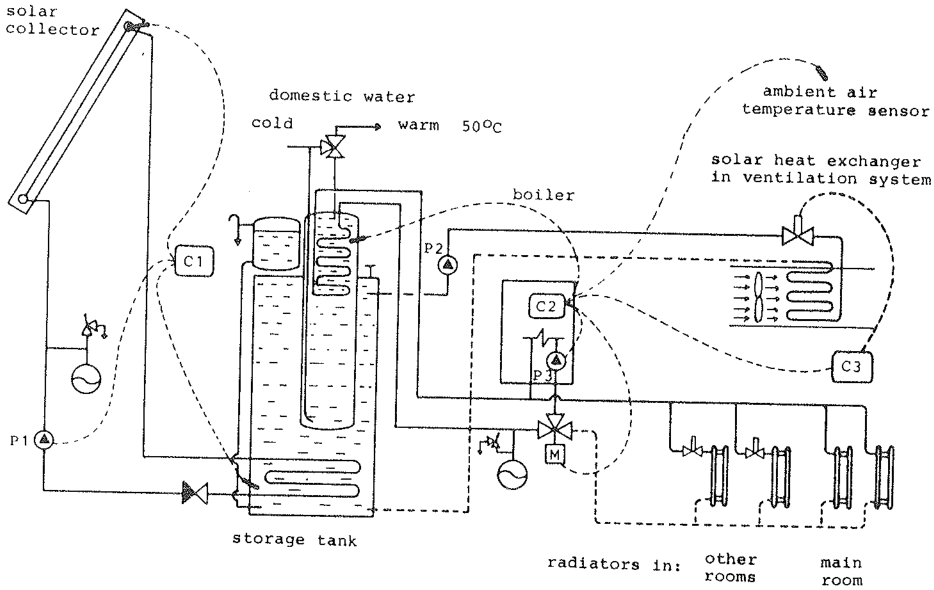


Fig. 5.9 System diagram, final design

The boiler will only operate on the DHW tank when the sensor in the top of the DHW tank calls for heat, i.e. if the temperature drops below the set-point of 40-50°C. If there is no need for either space heating or DHW postheating, the boiler will cut out automatically.

Solar energy for space heating is now delivered via a heat exchanger inserted in the ventilation system, which is a standard feature of many new houses in Denmark.

5.4.3 Operating modes

<u>Primary circuit</u>

The pump P1 in the primary circuit is controlled via a conventional differential thermostat with one sensor in the collector and another in the heat storage tank. The sensor in the heat storage tank is in a sensor pocket mid-way along the heat exchanger coil.

Overheating of the heat storage tank

At seldom occasions during the summertime where there is ample sunshine and no consumption, overheating may occur. The heat storage tank will boil at 100°C since it is non-pressurized. The primary circuit will boil at considerably higher temperatures (120 - 134°C) since it has a pressure of 2-3 atm. Overheating is avoided using night-time cooling of the heat storage tank. This is done by means of a special thermostat which prevents the pump from stopping if the heat storage temperature exceeds a given setpoint. The setpoint should be chosen according to the part of the store which can be cooled via the primary circuit, the heat loss coefficient of the store and the performance of the collector at 100°C. In the actual case a reasonnable setpoint is 75°C.

The hot water storage tank

The upper part of the immersed DHW tank serves as postheating tank.

This section will always be kept at the required DHW temperature (40°C or 50°C). If the temperature at the upper sensor drops below the setpoint, the boiler will work exclusively on DHW postheating until the required temperature has been achieved. It will then return to a position where it will be working on space heating if required.

Since the storage temperature during summertime may exceed 100°C, it is necessary to ensure that such high temperatures do not reach the domestic hot water taps. This is accomplished by installing a thermostatic mixing valve, which will mix cold and hot water to the required temperature of 50°C.

Space heating

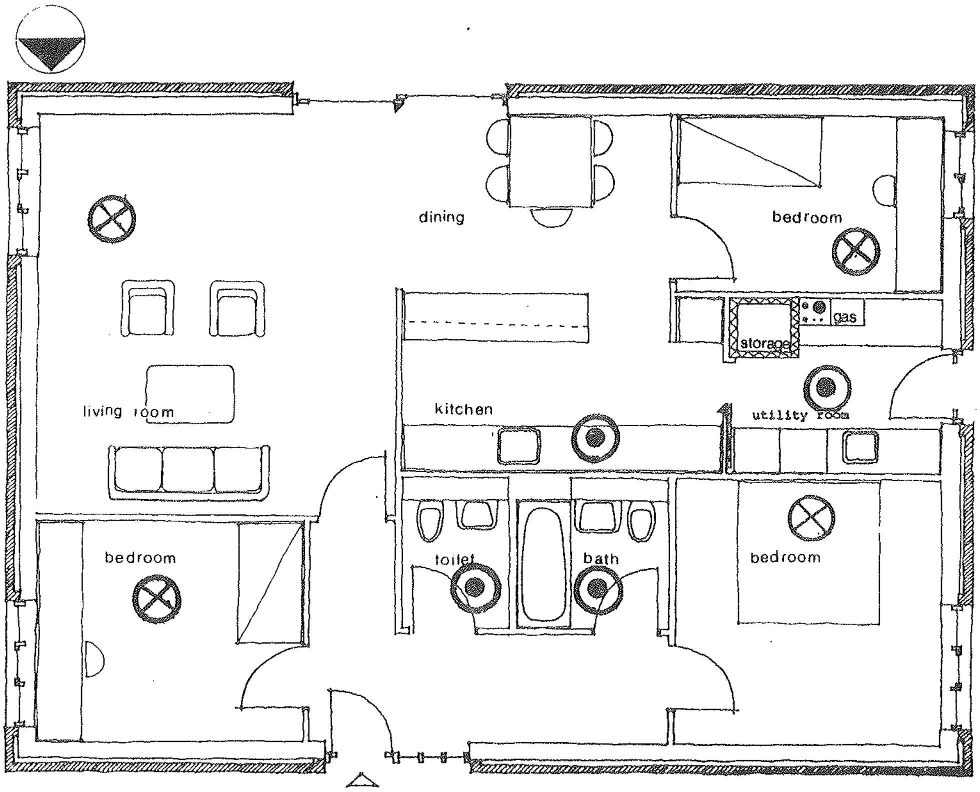
Solar energy for space heating is supplied via a separate heat exchanger inserted in the small ventilation system.

Such a ventilation system in a new air-tight dwelling is not regarded as a luxury, but more as a necessity. The ventilation system is normally fitted with heat recuperation. Fresh air is supplied to the living room and the bedrooms. Exhaust air is taken from the kitchen, the uitlity room and the bathrooms.

The solar heat exchanger is inserted into the channel for fresh air inlet to the living room and two of the bedrooms. Since there will often be a request for heating of the adults' bedroom, fresh air inlet to this room is bypassed the solar heat exchanger.

The output of the solar heat exchanger is controlled via a conventional thermostatic valve with a sensor in the main room. This room, which is a combination of kitchen, dining room and living room, represents 46% of the total heating load of the house. In practice a larger proportion of the total load will be covered via the heating system of this room. Room temperatures down to approximately 15°C will be accepted in the hall and the adults' bedroom. There will be no heating supply via the active heating system in these rooms, but the load will be covered via heat leakage from the adjacent rooms.

The thermostat which controls the output of the solar heat exchanger will modulate the water flow until the heat output is adequate. When the valve is 100% open (i.e. when solar energy is inadequate to cover the load), a



room with used air outlet

room with fresh air inlet

Fig. 5.10 Ventilation system, injection and exhaust air-ducts

small microswitch in the thermostat will activate the backup heating system.

Backup heating consists of a conventional radiator heating system with one radiator in each room (two in the main room). All the radiators except the ones in the main room are equipped with thermostatic valves, controlling the water flow to match the actual load.

When the solar room thermostat in the main room calls for backup heating, the boiler will heat up and the circulation pump P3 in fig. 5.9 will start. Backup heating will now occur with full water flow through the radiators in the main room. The heat extraction in the secondary s is controlled via the room thermostats which are fitted in each of these rooms.

When the temperature in the main room has been raised by approximately 1°C, the microswitch in the main room thermostat will open, and backup heating will be cut off.

The control of space heating can be summarized as follows:

> The setpoint of the main room thermostat is 21°C. Solar energy will cover the total load until the room temperature has dropped to 20°C. Then backup heating occurs. Solar heating will be cut off if the room temperature exceeds 22°C.

Thus it can be seen that solar heating always has preference, and even when backup heating is required, the extraction of heat from the store continues until the store has been cooled down to fresh air inlet temperature. This temperature (after heat recuperation) will vary between $10^{o}C$ and $20^{o}C$ depending on the ambient temperature.

Boiler

The main features of the boiler operation have already been given. It can be summarized as follows (see fig. 5.9):

When there is a request for space heating (from control C3), the boiler will work exclusively on space heating. The motorized valve M is activated so that it opens to the space heating side. The boiler temperature is automatically set according to the ambient temperature (typically $30-45^{o}C$).

When there is a request for DHW postheating, the boiler will work exclusively on DHW postheating irrespective of whether or not there is a a call for space heating. DHW postheating only occurs in very short periods. Through-out these periods, the boiler temperature is fixed at $60^{o}C$.

If there is neither a space heating nor a DHW heating demand, the boiler will cool down and the circulation pump P3 will stop. Idle losses from the boiler are then eliminated. The temperature capacity effect of the boiler is very little since the water content is only 2.5 l, and the total weight of the boiler, including the cabinet, is 49 kg.

5.5 COMPONENTS: MATERIALS, CONSTRUCTION AND INSTALLATION ON SITE

5.5.2 The Solar Collector

The solar collector is composed of the following main elements:

Two absorbers, each of 1x5 m^2 mounted in the module frame, insulation and glazing. The module size of the collector is 2m · 5m = 10 m^2. Within the main frame, profiles are fitted so that the glazing can be mounted in modules of 1m · 2m, see fig. 5.11. The glazing panels are of a low-iron type.

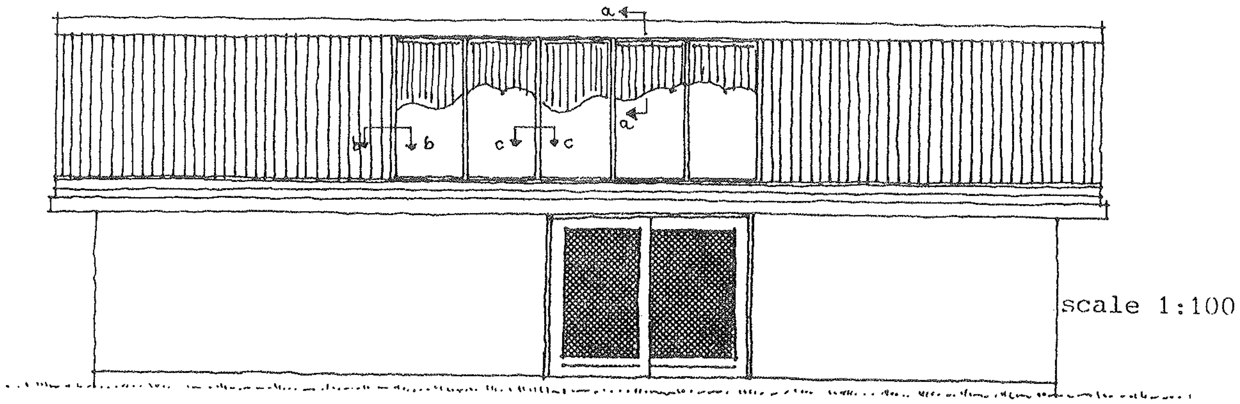


Fig. 5.11 South elevation of house with 10 m^2 of collector

Construction

The frame consists of standard aluminium greenhouse glazing profiles. The profiles are assembled using an aluminium welding technique. The frame is assembled on an underlying wooden frame, see figure 5.12. The absorber is

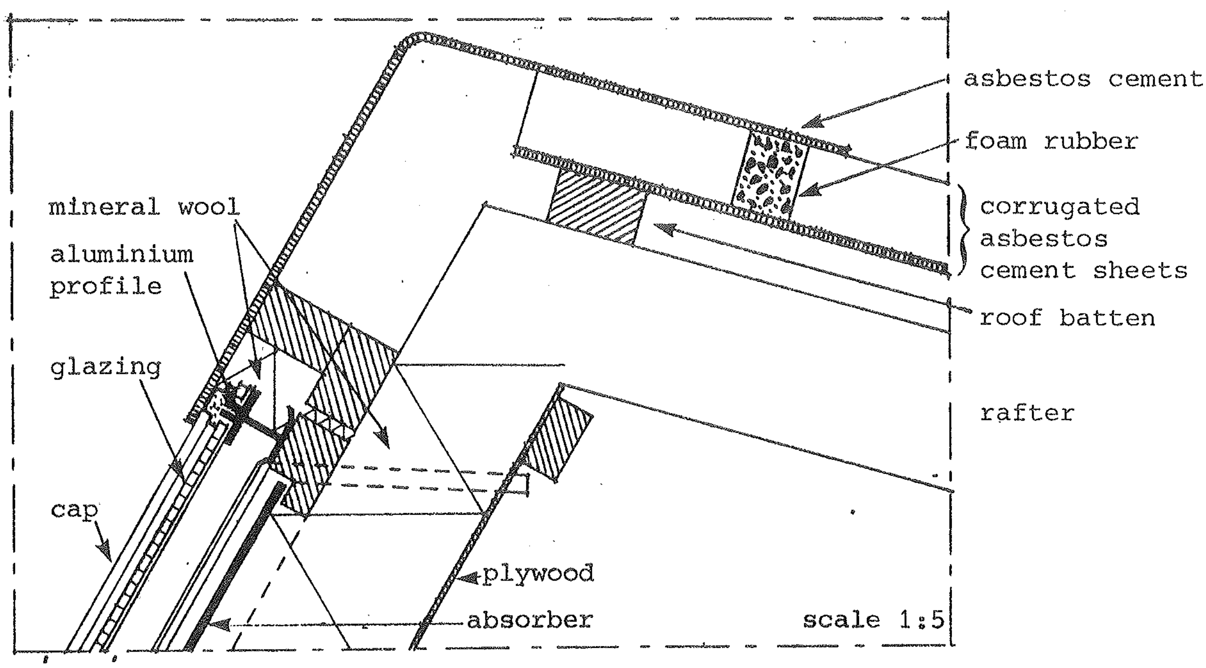
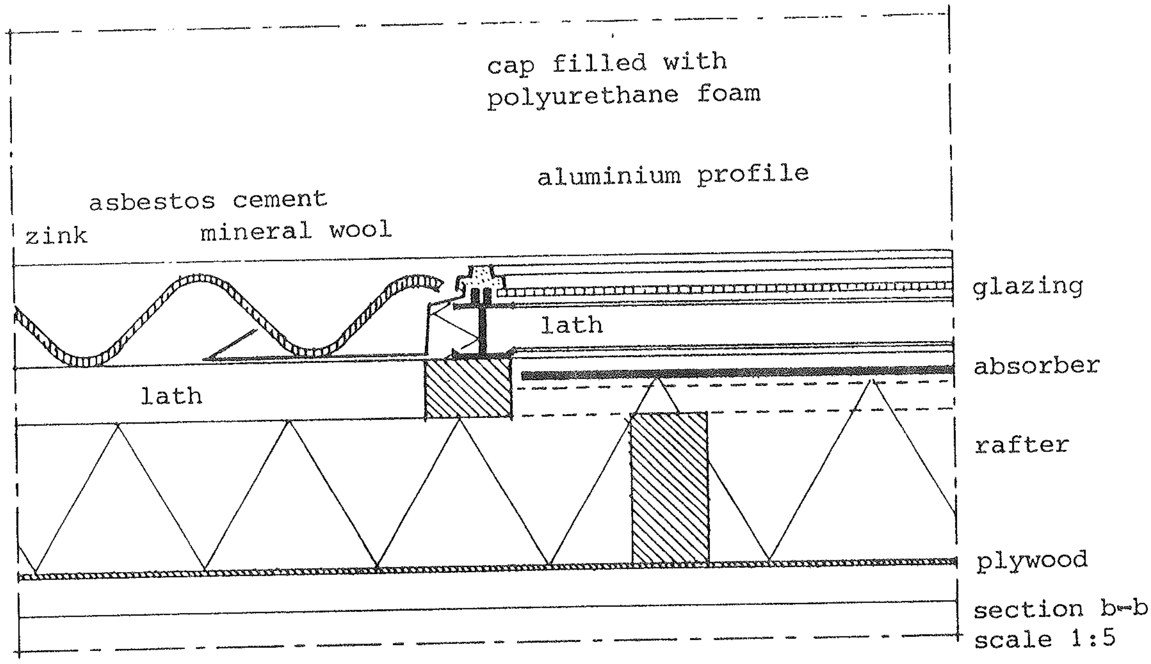


Fig. 5.12 Cross section through the collector roof. Section a - a.

mounted in a groove in this wooden frame. The absorber is then lying slightly below the lower edge of the aluminium profiles. The absorber may then stretch horizontally through the full length of the module (5 m). Two such absorbers will then cover the whole collector module giving a length of 5 m and a height of 2 m.



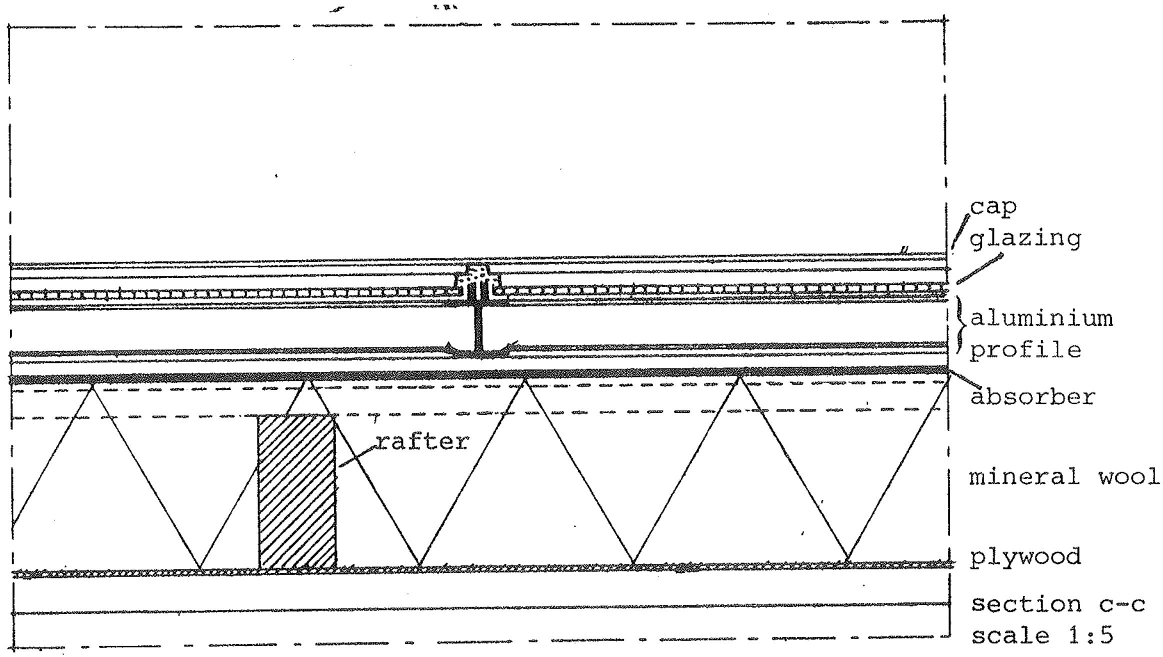


Fig. 5.13 Horizontal sections through collector

The back of the absorber is insulated with 125 mm of mineral wool. The edges are insulated with mineral wool under the flashing.

The glass and the flashing are fastened to the greenhouse profiles using standard greenhouse caps. The caps are, for this purpose, a little deeper than usual, and they are filled with polyurethane foam. In this way the effect of the aluminium profiles as a thermal bridges from the air in the collector to the ambient air is minimized.

The roofing material is waved asbestos. The material used for flashing is zink.

The flashing

The flashing up to the ridge of the roof is shown in fig. 5.12. The ridge itself is covered as usual with a ridge cap.

The air gap between glazing and the ridge cap is closed with a bituminous joint band. The use of zink flashing up against the gable and up against the normal roofing is traditional, except that the space below the zink profile is filled with insulation material.

5.5.3 The primary circuit

The primary circuit consists of 20 m 22/27 mm steel piping. The piping is insulated with 30 mm mineral wool.

The pump is a Grundfos UPS 20-60 with variable speed. The head at design flow, 10 m^2 · .8 l/min, is 57 kPa. Total pressure drop through the collector (two 1 · 5 m^2 elements in parallel), primary circuit and storage coil is 40 kPa. The pump may then work at speed no II (42 kPa at 8 l/min). The electricity consumption is then approximately 110 W.

The primary circuit is filled with a mixture of ethylene glycol and water, giving a freezing point of -30°C. The system is closed and pressurized. The system is filled with a dirt trap and a non-return valve to prevent heat loss via thermosyphoning during the night.

5.5.4 The heat storage tank

The general concept of the heat storage system is that the space heating store, DHW preheating and DHW postheating should be integrated. This is accomplished by immersing the DHW preheater tank down into the primary storage tank, see fig 5.8. The performance of the collector circuit may then benefit from the low temperatures of the incoming domestic water.

The layout of the store is seen at fig. 5.14. The postheating section of the DHW tank corresponds to 80 l. The total volume of the DHW tank is 280 l.

Both the main storage tank and the DHW tank are made of 3 mm steel plates. The sides of the main store are reinforced to stand the water pessure using horizontal bars welded on the inner sides (not shown). The DHW tank is fitted with a flange which fits the manhole in the top of the store.

Expansion

The storage system is fitted with open expansion. The connecting pipe for the expansion tank protudes from the bottom of the store in order to minimize heat losses from the store via the expansion tank. This tank is made of ordinary steel. Experiences re. corrosion of such open tanks in normal heating systems indicates that a life span of at least 10-20 years can be expected. Corrosion in the main store is not considered to be a problem, because the oxygen leakage to the store will be very limited.

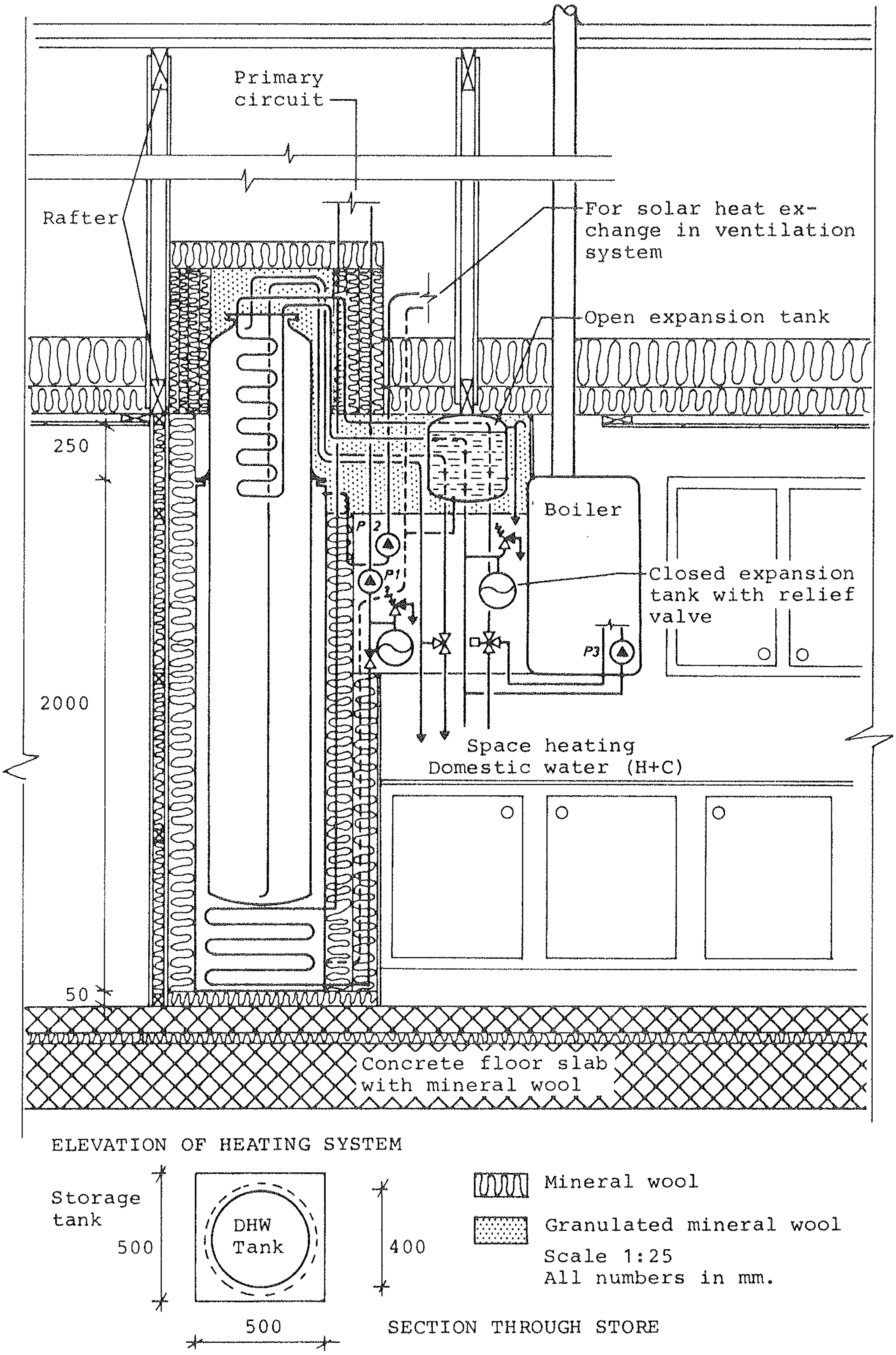


Fig. 5.14 Section through the storage system

Installation of the store

The store arrives at the site in two pieces: the main steel tank (uninsulated) and the DHW tank.

The corner of the utility room, where the store is to be situated, is prepared with 100 mm of mineral wool on the two walls adjacent to the tank. The floor is prepared with 50 mm of hard mineral wool. The store is put into place, and the DHW tank is mounted. The DHW tank may be put into place without removing the roof plates.

The boiler is mounted on the wall. A plywood plate is inserted between boiler and store. This plate will eventually carry the insulation in the upper part of the insulated components' cabinet.

Once all the pipewowrk has been finished, the insulation job is being completed. The two free sides of the store are covered with 100 mm of mineral wool and 200 mm of mineral wool are placed at the side where the pipework is hidden in the insulation. The insulation is covered with chip board.

The top of the store and the upper part of the insulated cabinet are filled with granulated mineral wool up to a level corresponding to lower edge of the roof insulation. The roof insulation is completed as far as the storage tank. Four layers of laminated tank insulation are fitted around the DHW postheater tank. The top is filled with mineral wool, and a 100 mm mineral wool plate finishes the job.

Heat exchangers

The storage system has two coil heat exchangers. For DHW postheating, 12.5 m of 13/15 mm copper piping is installed, giving a heat transfer coefficient of approximately 350 W/^{o}C. The primary circuit heat exchanger consists of 20 m of 20/27 mm steel pipe. The performance is approximately 450 W/^{o}C, corresponding to a 45 W/^{o}C $\cdot$ m^2 collector.

5.5.5 The Hot Water Pre-heating Circuit

Preheating of DHW with solar was dealt with in the former section, since the solar DHW tank is an integral part of the storage tank.

5.5.6 Auxiliary heating

The general requirements for the backup heating system is that it should have a high efficiency rate and low standby losses.

In the actual case the auxiliary boiler should not have a DHW tank or a DHW instant heating coil included. DHW instant heating coils are in any case problematic in Denmark because of the high lime content of the domestic water. Furthermore, since the auxiliary boiler is on standby for postheating DHW all the year round, it is preferable that the boiler has no standby losses at all (i.e. it is cold if there is no load).

Maximum efficiency is achieved by those boilers which condense the water content of the flue gases. Three boilers of this type were found on the Danish market: "Dancraft DEP 171/Hadwick 105", "Scan Unit" and "Nefit Turbo". All of them can work at low temperatures and can withstand the control strategy, i.e. frequent heating and cooling. The "Nefit Trubo" boiler was chosen for this case study, primarily because it is intended for wallmounting. Furthermore, it has the advantage that the thermal capacity is very low, 2.5 l of water and a total weight of 49 kg. The figures for the Dancraft is 64 l and totally 131 kg. The Scan Unit has a water content of 40 l and a total weight of 200 kg.

The auxiliary space heating system consists of traditional radiators. In each room radiator capacity corresponding to the total load of the room is installed. The maximum supply temperature requested is 60°C corresponding to an ambient temperature of -12°C.

An air heating system as distribution system for back-up heating was considered. It was not chosen since there is little experience of such systems in Denmark. Furthermore, an air heating system would exclude individual control of the room temperature and it was felt that this was undesirable.

It should be mentioned that the choices of either auxiliary heat distribution system has almost no influence on the solar system layout, performance or economy. In both cases solar energy for space heating is delivered via a separate water to air heat exchanger inserted in an existing air duct. Backup heating might even be via direct electricity (panels in each room). Finally, if the house was not equipped with a ventilation system, the separate solar heat exchanger could have been installed as a radiator, as presupposed in the first design. This solution is also compatible with the water-to-air heat exchanger solution as regards performance and economy.

5.5.7 Controllers

The differential thermostat, C1, for the primary circuit is of a conventional type, see fig. 5.9. The actual unit chosen has an extra sensor, usually mounted at the top of the store. Direct reading of the three temperatures (collector, bottom and top store) is possible via a digital display.

The control unit, C2, is an optional feature of the boiler. The control unit, C3, is a modified room thermostat with an on-off output possibility, available from Danfoss.

5.5.8 Assembly on site

The procedures for assembling the collector are described in section 5.5.2. The procedures for assembling the store and the rest of the system are described in section 5.5.4.

5.6 SYSTEM PERFORMANCE

5.6.1 Introduction

The system modelling work has served two main purposes: sizing the main components and assessment of the system performance.

Regarding system performance, the objective is to reach a performance level between 250 and 400 kWh/m^2. A performance in this region ensures a reasonable cost-effectiveness. This issue is discussed in more detail in section 5.7.4 "Cost effectiveness".

The dimensioning of the system components is limited to the main components: solar collector size and type, storage size and the capacity of the solar space heating heat exchanger. The effect of variations in the collector tilt is also investigated.

The dimensioning of the rest of the system components is done based on previous experience, i.e. using some approximations. The dimensioning of these components is normally not critical to either system performance or to the total investments, given that choices within a reasonable region are made. These "reasonable" choices are:

Collector: single-glazed with selective absorber.

Primary circuit: flow 0.8 - 1.0 l/minute · m^2 collector.
Insulation: 25 mm of insulation.

Storage tank: Insulation: 100 mm mineralwool as a minimum when situated within the heated building envelope.

The specific storage volume (l/m^2 collector) has been fixed to a value of 50 l/m^2. Previous modelling work using the SVS simulation code shows that specific storage volumes down to this figure can be accepted without significant penalties on system performance. This is regarded as a preliminary conclusion since modelling work using a model with a stratified storage system (i.e. using the EMGP2 model) may lead to slightly different conclusions. A value of 50 l/m^2 is regarded to be on the safe side since the modelling of DHW only systems with a stratified storage model meant that lower specific storage volumes were acceptable.

5.6.2 Description of the simulation model

The simulation model used for modelling work is the SVS model based upon programs developed for the "Zero Energy House" by Torben Esbensen and for solar heating systems by Henrik Lawaetz at the Thermal Insulation Laboratory.

The program consists of a number of subroutines, which either model components or have mathematical functions. The program is quasi-stationary, meaning that energy flows within the timestep are supposed to be stationary.

One main drawback of the programme, as it exists now, is that it considers the storage tank to be non-stratified. (Stratified DHW systems may be modelled). This means that detailed studies of the lay-out of the heat storae tank is not possible. Similarly, it is not possible to model the influence of different control strategies for the solar space heating system since the effect of variations in the return temperature from the heating system has not been fully taken into account.

A more detailed description of the SVS model is given in reference 5.5.

5.6.3 Predicted performance data

Variations in the size of the main components are made based on weather data from the new Danish Reference Year (5.4), the hourly heating loads of the actual house, and a DHW consumption of either 100 l/day, 150 l/day or 200 l/day.

The reference values used for the simulations are shown in fig. 5.1.5.

Climate:	Danish Reference Year 1020 kWh/m^2 · year on horizontal plane.
Heating load:	7360 kWh/year
Hot water load:	200 l/day heated from 8^{o}C to 48^{o}C (3370 kWh/year net DHW load)
Solar collector:	tilt: 56^o from horizontal orientation: south efficiency: $= 0.82 - 5.0\ (T_m - T_a)/E - 0.011\ (T_m - T_a)^2/E$ where T_m = mean fluid temperature (^{o}C) T_a = ambient temperature (^{o}C) E = solar intensity (W/m2)
Storage tank:	- specific volume 50 l/m^2 collector - insulation: 100 mm of mineral wool - non-stratified, temperature of store and immersed DHW tank always the same
Heat distribution:	- capacity of solar heat exchanger W/^{o}C

Fig. 5.15 Reference values for system modelling

As discussed in section 5.4.3 "Operating modes", it can be argued that if solar energy for space heating is supplied to the main rooms, there will, in practice, be no auxiliary heating load if the solar system can cover the load in these rooms. These rooms are: kitchen/dining/living room (46% of the load) and the two smaller bedrooms (19% of the load). The control system actually does not allow auxiliary space heating to occur if solar space heating satisfies the load in the main room. Consequently, the modelling is made on the same assumptions.

Collector area

The effect of variations in the collector area is shown in fig. 5.16. It is seen that a threshold of 250 kWh/m^2 requires collector areas of between 8 and 13 m^2 depending upon assumed hot water load.

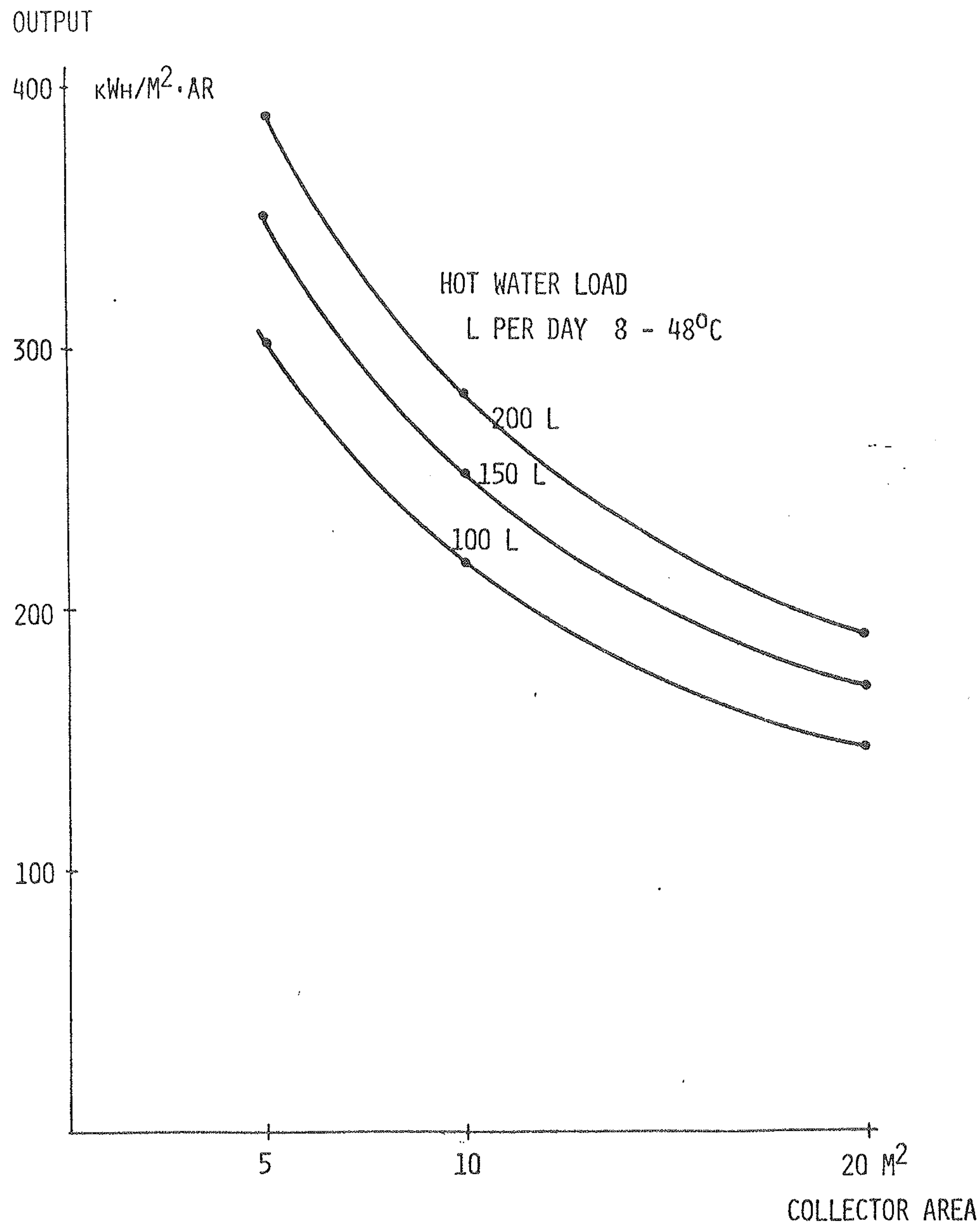


Fig. 5.16 Output for variations in collector area

5.7 SYSTEM COSTS AND COST EFFECTIVENESS

5.7.1 Introduction

In this section both the overall and the more detailed costs will be discussed. The solar energy system has been costed on the basis of the case study house described in section 5.2.

The system costs have been established by the contractor, Dansk Solvarme. The company both produces and installs solar energy systems. Experiences from other jobs indicate that the lowest total price is achieved if the installation job is undertaken either by the manufacturer or by a contractor who works closely with him.

System costs are shown for a 10 and a 20 m^2 system in two cases. In section 5.7.2 a cost analysis of a 20 m^2 one-off system is presented, and in section 5.7.3 a cost analysis of 100 identical systems (10 m^2 and 20 m^2) on one site is presented. It is then indicated to what level costs might be reduced if the manufacturer could utilize the full production capacity of the present facilities, and the cost-effectiveness of the whole system is discussed. As a basis for this, a cost function for variations in system size is set up. The system size giving the best performance level per invested ECU is identified.

Finally, the economical situation for the private consumer is discussed, taking into account current fuel prices and economic incentives presently available in Denmark.

The cost figures are given in dcrs. followed by the equivalent figures in ECU, 1 ECU = dcrs. 8.04. The price level is as at January 1983. All prices are exclusive of VAT (22%).

5.7.2 Cost of the Solar Heating System

The detailed costs of components, etc. can be seen in section 5.7.3, where the cost breakdown for 100 systms is shown. In this section the cost predictions have been revised to indicate what the costs for a one-off system would be. The basis is still a new-built house. The system has a 20 m^2 collector, and a storage volume of 1000 l.

	dcrs	ECU
A. Solar collector, 20 m^2	21,295	2,650
B. Storage tank, 1000 l	11,360	1,413
C. Other components	5,116	636
D. Materials for installation of primary circuit	1,826	227
E. Transportation	850	106
F. Installation costs	8,748	1,088
G. Control of system function, etc.	959	119
H. Insulated cabinet to cover components	900	112
Total costs	51,054	6,351
Saved DHW tank, installed	4,300	535
Net overall costs for solar heating system	46,754	5,816

Capacity of the solar space heating capacity

In figure 5.17 the influence of the heat exchanger size is shown. It is seen that a the heat exchanger capacity of 30 - 50 W/°C is adequate. It should be noted that this value is considerably lower than previous modelling work at TIL has indicated. The previous work was done on houses having a higher load than this case study.

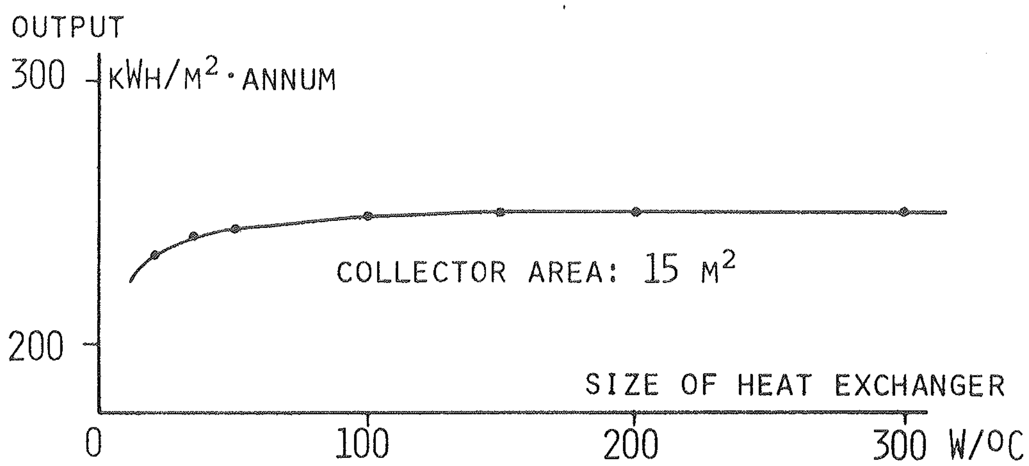


Fig. 5.17 Annual system performance depending on size of solar heat exchanger.
(Note: Collector area 15 m^2.)

A required heat exchanging capacity of only 35 W/°C means that a standard postheating heat exchanger for small heat recuperation systems can be used. If the solar heat exchanger was installed as a radiator, the required size would be only 645 mm times 1000 mm.

Collector tilt

Influence of variations in collector tilt is seen in fig. 5.18.

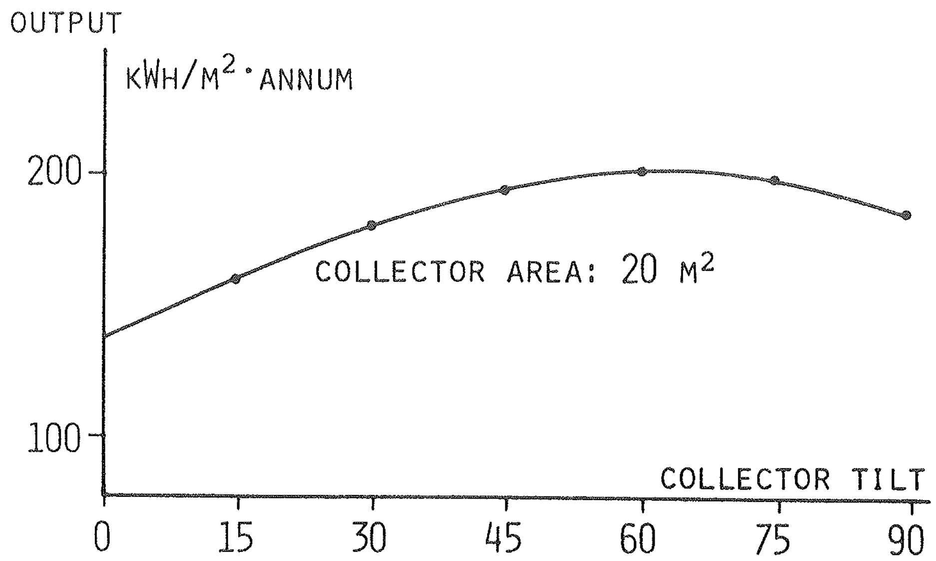


Fig. 5.18 Annual system performance depending on collector tilt.

The optimal tilt is seen to be 60° with very little variation in output between 45° and 75°. The decrease in performance, if the tilt is left at 20° (typical roof tilt of one-storey houses), is 17%.

Performance of final system layout.

As discussed in section 5.7.4 "Cost Effectiveness", the optimal collector area is 10 m^2. The annual performance for this system, given a DHW load of 150 l/day, is 255 kWh/m^2 collector. The total space and water heating load of the house is 9890 kWh, out of which the solar system covers 26%.

If the DHW load were 200 l/day, the solar energy system would cover 27% of the total load, 10,730 kWh. The output of the solar energy system then corresponds to 285 kWh/m^2.

5.7.3 Costs of 100 identical systems

The following cost breakdown was originally done for a 20 m^2 system with a storage tank of 1000 l. To analyse the influence of smaller system sizes, the costs of a 10 m^2 system has been included as well. The main difference as compared to the 20 m^2 system is that only one instead of two 10 m^2 collector elements is now being installed. The storage size decreases to 500 l.

		20 m^2	10 m^2	
		dcrs	dcrs	ECU
A.	Solar collector Partly prefabricated elements type KP10 selective, each 10 m^2			
	- Selective absorber,	14,000	7,000	870
	- Casing, flashing inclusive	5,245	2,630	327
		19,245	9,630	1,197
B.	Storage tank Steel tank (3 mm), with 280 l DHW tank immersed, with heat exchangers	7,600	6,500	808
	Floor space for store (3,000 dcrs/m^2)	3,000	1,500	187
		10,600	8,000	995
C.	Other components			
	- Expansion tank, open	100		
	- Closed expansion system (collector circuit)	470		
	- Air vent	36		
	- Closing valves, 3/4"	42		
	- Dirt trap, 3/4"	58		
	- Non-return valve, 3/4 "	44		
	- Pump, Grundfos UPS 20/60	590		
	- Differential thermostat JN 105	950		
	- 2 bottom cocks	39		
	- 2 sensor pockets	55		
	- Mixing valve, Caleffi 520	230		
	- 12 m 16/21 steel pipe with fittings and insulation (for solar heat exchanger)	420		
	- Pump, Grundfos UPS 15/35	510		
	- Solar heat exchanger to be installed in heat recuperation system	695		
	- Three way motorized valve, 1/2" HB-Erie	555		
		4,794	4,750	591
D.	Materials for installation 20 m 22/27 steel pipe with fittings and insulation, storage insulation and 25 l glycol	1,660	1,550	193
E.	Transportation (estimated)	750	750	92

F. Installation costs			
- Solar collector	4,160	2,400	300
- Storage tank	520	500	62
- Piping and insulation	2,085	1,900	236
- Electrical connections	440	440	55
- Solar heat exchanger, piping	780	780	97
	7,985	6,020	750
G. Control etc.			
- Filling up primary circuit with glycol, control of functions after 30 days and one year	800	800	100
H. Insulated cabinet to cover components (installed)	600	600	75
Total costs:			
Items A-H incl.	46,434	32,100	3,993
Saved DHW tank, installed	4,300	4,300	535
Extra costs for solar system	43,134	27,800	3,458

Further cost reduction

The basis for the costs given above is the present annual production of the manufacturer. This production is far below the full production capacity of the facilities. The annual production capacity is in the region of 40,000 m^2 collector, corresponding to 4000 combined 10 m^2 systems with storage tanks, etc.

Given full production, it is estimated that the costs of collector and storage tank can be reduced by 30%. The costs for other components (fittings, etc.) may be reduced by a factor of 15% because the necessary components may now be bought in larger batches. The on-site costs (items E-H incl.), are not changed since the installation job is unchanged.

The total costs for 50 systems each of 10 m^2 built on one site given full utilization of production capacity at the manufacturer is now:

Total costs (dcrs): = 27,800 - 0,3 (9630 + 8000) - 0.15 (4750)
= 21,800 dcrs.
= 2,710 ECU

This corresponds to a total cost reduction of 22%.

It should be emphasized that these figures are based on the system construction and layout as described in this report. Further cost reductions may be possible with further development of the collector, of the storage tank and perhaps even development of a totally new design concept.

5.7.4 Cost effectiveness

In section 5.6.3 the system performance for variations in collector size and DHW load is shown (fig. 5.15). In order to identify the optimal system design (maximum output per invested ECU), a price function for variations in collector size must be established.

Price function

The major costs are connected to the collector and the storage tank. In both cases, the price function is far from linear for changes in system size. The price function shows major jumps at the point where the collector changes from one unit to two.

Collector

As described in section 5.5.2, the maximum size for the partly pre-fabricated collector unit is 10 m^2. If larger collector areas are requested, two units are required.

The price for one collector element of 10 m^2 is 12,030 dcrs., installation included. The marginal costs of one m^2 absorber is approx. 600 dcrs., and the cost reductions possible by reducing the element below 10 m^2 will not be much higher than the reduction in absorber costs, i.e. 700 dcrs.

The price function for the collector is then:

$$P_c = 5{,}030 + 700 \cdot A \text{ (dcrs) (A varies 0 - 10 } m^2\text{)}$$

$$= 626 + 87 \cdot A \text{ (ECU) (A varies 0 - 10 } m^2\text{)}$$

Based on a total price of 20 m^2 collector of 23,405 dcrs., the price function for larger areas is:

$$P_c = 9{,}405 + 700 \cdot A \text{ (A varies 10 - 20 } m^2\text{) sk}$$
$$= 1170 + 87 \cdot A \text{ (A varies 10 - 20 } m^2\text{)}$$

Heat storage tank

Investments for three storage sizes were:

1260 l - 7950 dcrs.
1000 l - 7600 dcrs.
720 l - 6900 dcrs.

Where V = storage volume in litres, the heat storage price function P = 5500 + 2 · V is a good approximation. When space for the store (3000 dcrs./m^2 floor area) is included, the price function changes to

$$P_s = 5500 + 5 \cdot V \text{ (dcrs.)}$$

A specific storage volume of V = 50 l/m^2 · A means that the price function can be reduced to:

$$P_s = 5500 + 250 \cdot A$$

The investments in the rest of the components and their installation is not considered to be effected when considering system sizes within a narrow margin (say 8 - 20 m^2).

The final price function is now:

A between 0 and 10 m^2:

$$P_{tot} = 18{,}300 + 950 \cdot A \text{ (dcrs)}$$
$$= 2{,}276 + 118 \cdot A \text{ (ECU)}$$

A between 10 and 20 m^2:

$$P_{tot} = 24{,}134 + 950 \cdot A \text{ (dcrs)}$$
$$3{,}001 + 118 \cdot A \text{ (ECU)}$$

These price functions are plotted into the optimisation diagram, fig. 7.18, together with the performance functions.

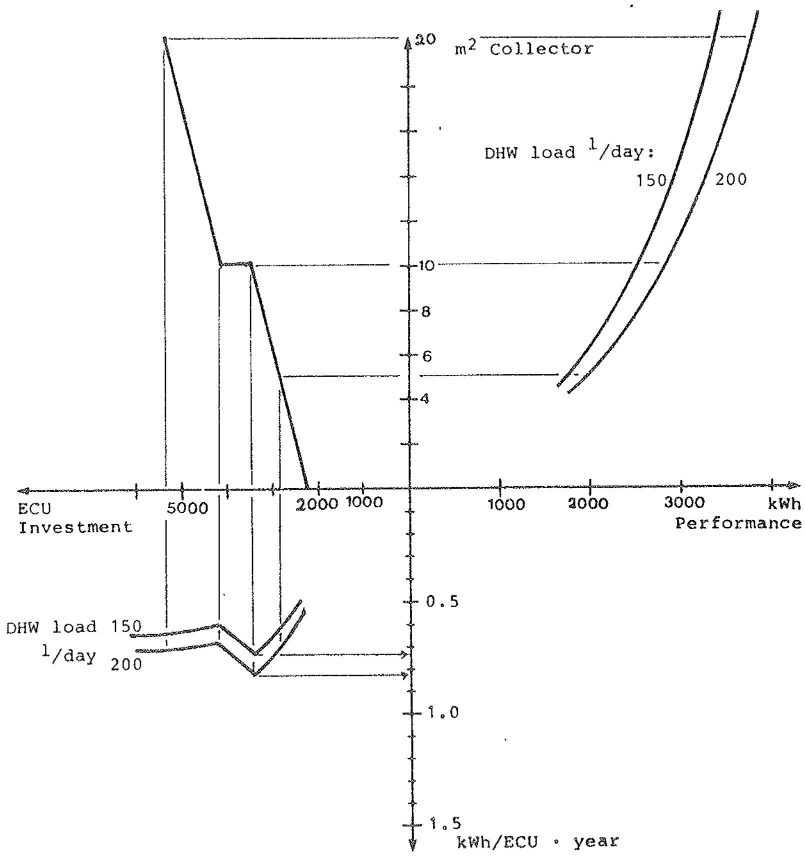


Fig. 5.19 Optimisation DHW + SP, final design

It is seen that the optimal design is a 10 m^2 system. It can, on the other hand, also be seen that system sizes up to approx. 15 m^2 are attractive if such a collector could be supplied in one unit.

Costs versus savings for the consumer

The economic situation for a consumer buying a new house with a solar energy system has been assessed. This is based on the present situation in Denmark regarding tax rates, rates of interests, fuel prices and available incentives for installing a solar system.

The extra costs for the optimal 10 m^2 system has been shown to be 27,800 dcrs VAT exclusive. In Denmark this price will be reduced due to a 30% subsidy, which is given to people installing a solar heating system. When 22% VAT and incentives are taken into account, the costs can be established as:

costs inclusive of VAT

Total costs for a 10 m^2 system 32,100 · 1,22 =	39,160 dcrs
Saved DHW tank installation 4,300 · 1.22 =	- 5,200 dcrs
Subsidy: 30% of total costs 39,160 =	11,750 dcrs
Net overall cost for private consumer =	22,210 dcrs

The extra annual costs for financing a net overall cost of 22,210 dcrs is 3,330 dcrs/annum based on a 14% loan over 30 years. When tax deduction of interests is taken into account, the net costs can be calculated to be 1470 dcrs/year for the first year of operation, based on a marginal rate of taxation of 60%.

With the present fuel prices of gas or oil (3.4 dcrs/l), the costs for one kWh produced by the proposed high-efficiency boiler is approximately 0.40 dcrs/kWh. The annual savings of 2550 kWh then correspond to 1020 dcrs. If backup heating was provided with electricity, the annual savings would rise to 1860 dcrs, based on the present electricity price of 0.73 dcrs/kWh.

If the boliler was not a high-efficiency one, the value of saved energy would increase. The high-efficiency boiler has almost no idle losses, whereas a typical boiler on the Danish market has an idle loss of 300 W or 1300 kWh during six summer months.

A traditional boiler as backup heating would therefore mean an increased annual saving due to the solar heating system of 1300 kWh. The total annual saving due to the solar heating system would then rise from 2550 kWh to 3850 kWh. The value of this is then 3850. 0.40 dcrs = 1540 dcrs.

It can be concluded that if backup heating is gas (or oil) as presupposed in the case study, the annual savings the first year of opertion are lower than the extra annual costs. If backup heating is electricity, there is a positive balance in favour of the solar energy system even during the first year of operation. This is also the case if backup heating is not a high-efficiency unit but a more traditional boiler.

5.8 OPTIMISATION METHOD AND SYSTEM SIZING

Generally, this present system design should be seen as a further development based on previous experiences with combined solar heating system, (5.1) and (5.2). Based on given constraints, the system has been designed and sized towards an "optimum design".

5.8.1 Introduction

In this case, optimality is defined as maximum output per invested ECU, (e.g. kWh/ECU · annum) should be as high as possible. Furthermore, the given contraints have some impact on the optimality concepts. A given design cannot immediately be accepted as optimal if it is based on processes of manufacturing that are not yet developed. Similarly, the traditional way of installing hot water systems has some impact on system design. DHW systems in Denmark are, for instance, always pressurized systems, where possibilities for non-pressurized systems could lead to simpler and cheaper designs.

5.8.2 Optimisation method

The optimisation method is, as previously mentioned, based on the concept "maximum output per invested ECU", see (5.8). Such an optimality criteria is useful when discussing the situation for the private consumer. He will normally focus on the payback period or on the balance between extra initial expenses and savings during the first years after he has made an investment in an energy saving measure. If the situation in the immediate future is that extra expenses on loans, etc. are significantly higher than the value of saved fuel, he will be reluctant to make the investment. This may even be the case if some present value calculations over a given period based on certain predictions re. inflation, fuel prices, etc. show a positive balance in favour of the investment.

It should be noted that the optimisation criteria adopted would tend to be rather conservative. If the value of saved fuel pays for the extra expenses the first year, this can be expected to be the case in the following years, given that the fuel prices do not fall.

5.8.3 System sizing

The system sizing has been done by using some rules of the thumb for sizing some components that are not crucial to system cost-effectiveness. This applies, for instance, to insulation thickness of piping and heat storage tank, flow in solar circuit, size of heat exchanger, etc. If some minimum criteria are respected, the system performance will not be affected, and the costs in question are in any case not very high.

The main parameters of the system are collector size, storage size, space heating and DHW load. Those parameters have a large influence on costs and/or performance. They are therefore examined in more depth. This is done using simulation models to model the performance for a given system layout. Similarly, the load of the house is modelled. The results of the system sizing work can be seen in section 5.5 and 5.6. The costs for the collector and the storage tank are investigated in order to achieve minimum costs.

5.9 HOUSE: INITIAL DESIGN AND REVISIONS

5.9.1 Introduction

This section includes a short discussion of the few revisions that were made to the case study house, and how combined solar energy systems of the type shown in this report can be installed in other house types, i.e. houses with an occupied top storey.

The influence of changing the present house type towards a house more adapted for passive solar energy is shown in section 5.12.

As shown in section 5.2.2 new housing in Denmark shows a wide variation in types and sizes. Furthermore, it is difficult to give a very clear picture of the future new housing sector, since the present building rate is very low.

5.9.2 Initial design and basis for selection

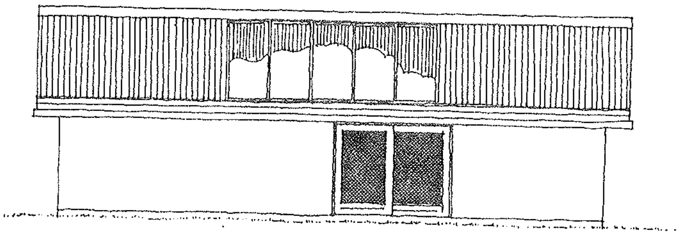
The initial house design is shown in fig. 5.1 and described in section 5.2.3. This house is regarded as typical of a rather large proportion of the low-to medium cost housing. The house can optionally be supplied with a solar energy system, and for that reason the roof facing south has a tilt of 56^{o}.

5.9.3 Problems and revisions

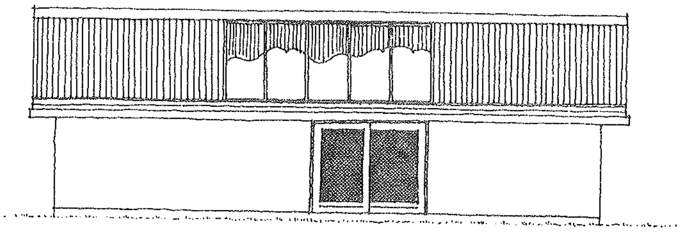
Basically, only one thing was changed in order to integrate the solar system. The door between the utility room and the kitchen was changed to a sliding door. This was done because the storage tank is situated close to the passage between the two rooms, and circulation is improved by using a sliding door.

Further changes were made to the floor plan so that the house could be used in a more flexible way in a given site layout. An optional floor plan was developed, where access to the house is possible from the south, see fig. 5.5 in section 5.3.2. Furthermore, one gable facade now has no windows. Finally, the window area facing south is increased, and the window module is adapted to the solar collector module, 1.0 m. The architectural expression of the south facade is heavily influenced by the collectors in the roof. In fig. 5.20 the south elevation for different collector sizes and window geometries is shown. The upper two pictures represent the basic house design as shown in fig. 5.1.

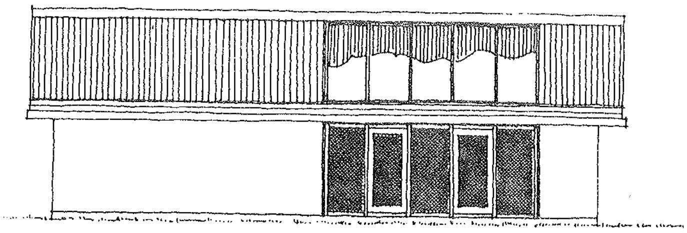
10 m^2 coll., 1 m module
6 m^2 window, 1.4 module



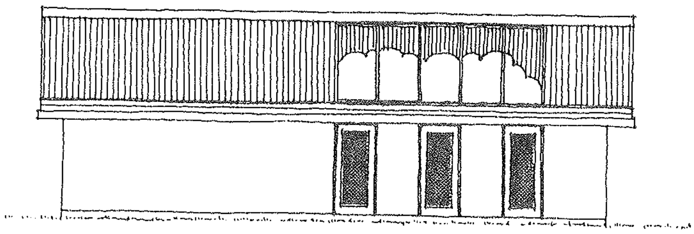
10 m^2 coll., 1 m module
6 m^2 window, 1.4 m module



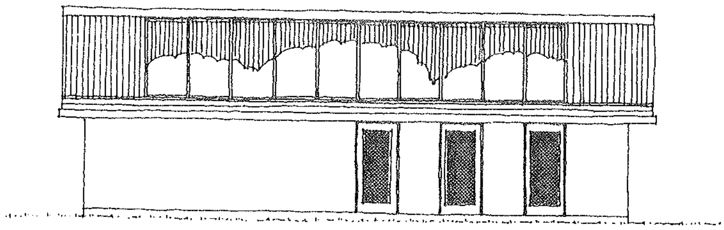
10 m^2 coll., 1 m module
10.5 m^2 window, 1 m module



10 m^2 coll., 1 m module
6.3 m^2 window, 1 m module



20 m^2 coll., 1 m module
6.3 m^2 window, 1 m module



28 m^2 coll./glazing, 1 m module, 10.5 m^2 window, 1 m module.

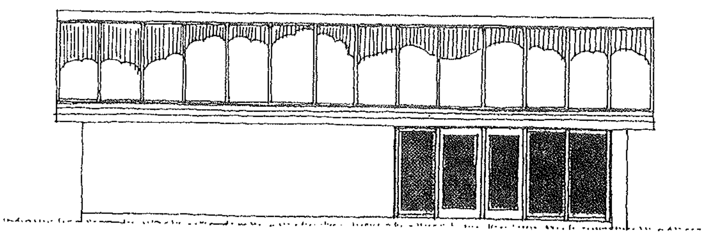


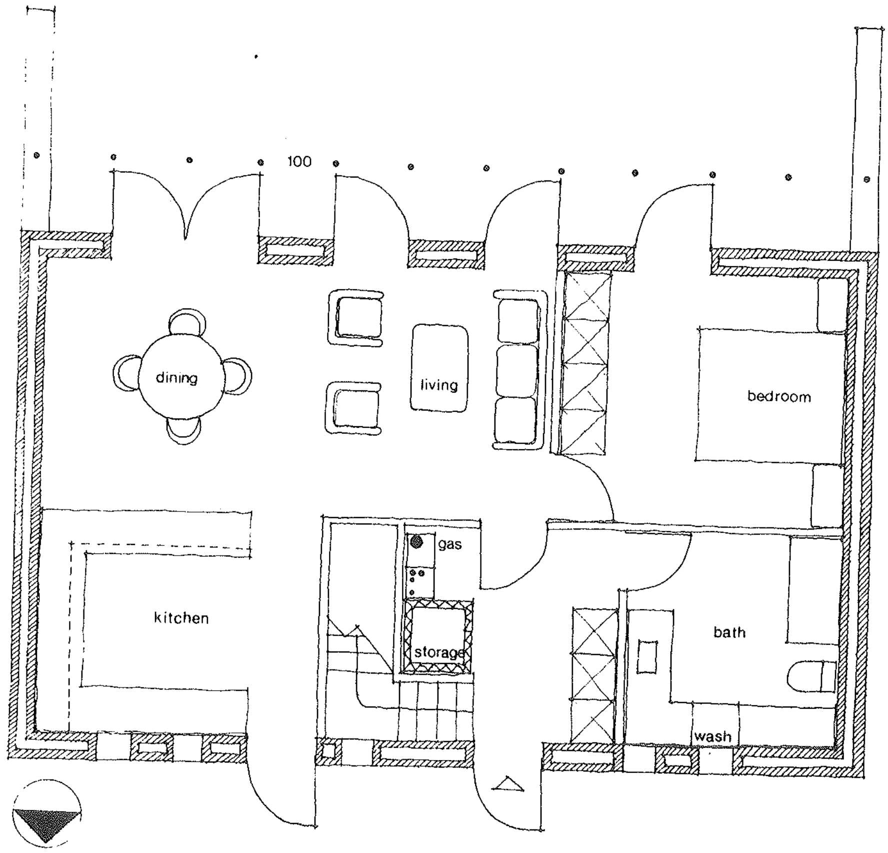
Fig. 5.20 South elevations for different collector/window options

Alternative house design

Together with single-storey houses, houses with an occupied top storey (1 1/2 storey) represent almost all new housing in Denmark.

The width of the roof facing south of a 1 1/2 storey house will typically be 5 - 6 m, and the tilt will be 40 - 60° from horizontal.

In fig. 5.21 and 5.22, a possible way of integrating the collector and the storage tank in such a house is shown in fig. 5.23 The collector is the 1 · 5 m^2 unit developed in the DHW only case study, see (5.8). The south elevation of a 1 1/2 storey terrace houses with 5, 10 and 15 m^2 collector is shown in fig. 5.23. The collector and the window module are the same, 1.0 m.



scale 1:100

Fig. 5.21 Ground floor of 1 1/2 storey terraced house

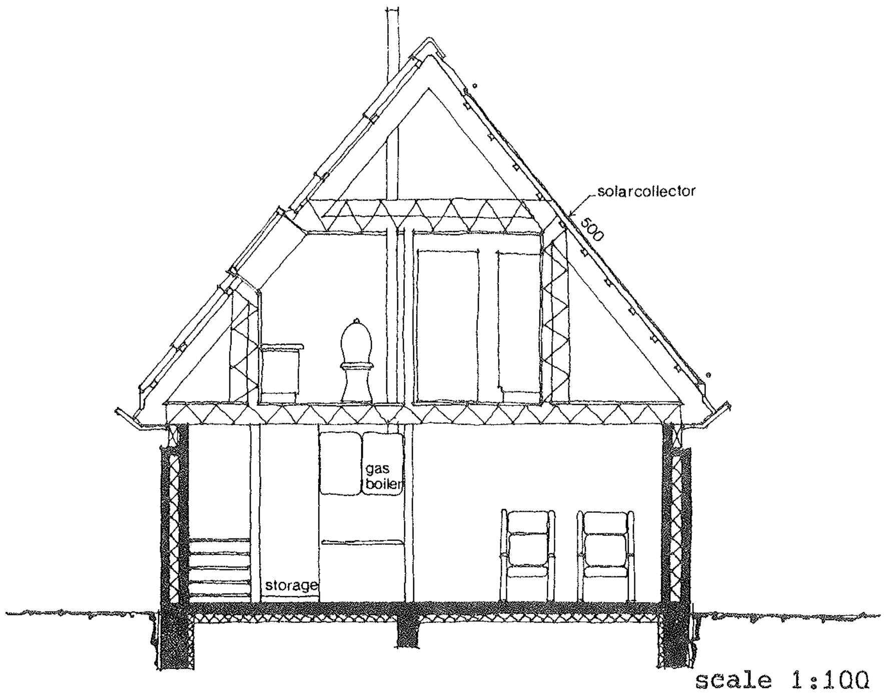


Fig. 5.22 Section A-A through 1 1/2 storey house (see fig. 5.21)

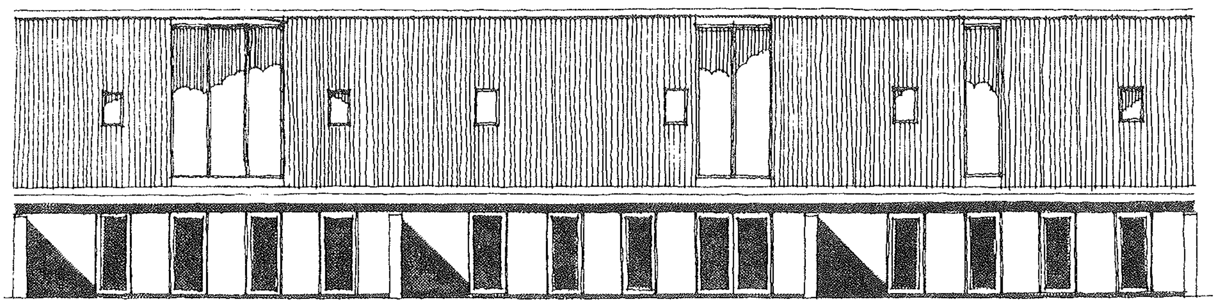


Fig. 5.23 1 1/2 storey terraced houses with 5, 10 and 15 m^2 of collector.

5.10 SYSTEM: INITIAL DESIGN AND REVISIONS

5.10.1 Introduction

The actual system operation and performance from several combined systems for space heating and DHW have been analysed in order to point out the main penalties causing operational problems and decrease in performance, (5.1) and (5.2). The use of simulation models has a very important role to play in this process of system design, evaluation of system performance and definition of new improved design concepts. Using simulation models, it is possible to scrutinize system performance and point out which parameters have a major influence on system performance and which ones havn't. There are then good possibilities that the next design to be tested in full scale will show major improvements over the previous experiment.

The main problems with the early systems were:

1. They were too complicated. This lead to an expensive system with poor reliability. The installation job was quite complicated, and special assistance had to be offered in order to ensure that the expected system operation was achieved.

2. The heat losses from the system were too large having a major influence on system performance. Heat losses occured primarily from the storage tank and from components (pumps, valves, etc.). The main reason for large heat losses from the storage tank was the effect of thermal bridges. Heat losses from the components are significant since most of them cannot be insulated.

3. It has often been experienced that the backup heating system has a negative influence on the performance of the solar energy system.

   This is often the case if the same space heating system is shared between the solar heating system and the backup heating system. In that case solar energy stored in the storage tank cannot be utilized for space heating at temperatures lower than the return temperature of the heating system (e.g. 30 - 40 °C). Ideally, it is desirable that solar energy is used down to a storage temperature equal to the room temperature.

   The analysis of the performance of one of the early system designs, the Greve system, resulted in the conclusion that the actual performance of the 50 m^2 system (5400 kWh/year) could also be achieved with an improved system using only a 15 m^2 collector. The major improvements are: improved storage system with decreased heat losses, separation of the solar heat exchanger and the space heating heat exchanger and a drastic decrease in piping length both in primary circuit and in secondary circuits. Finally, a collector with improved performance, such as are now available, also contributes significantly to the improved performance. The same improvements, but with unchanged system size (50 m^2) would improve the performance from 5400 kWh to 6900 kWh/year (reference 5.1).

5.10.2 Initial design and basis for selection

The necessary improvements to system layout emerging from the analysis of early systems, are to a very large extent reflected in the 1st design system layout as shown in fig. 5.24

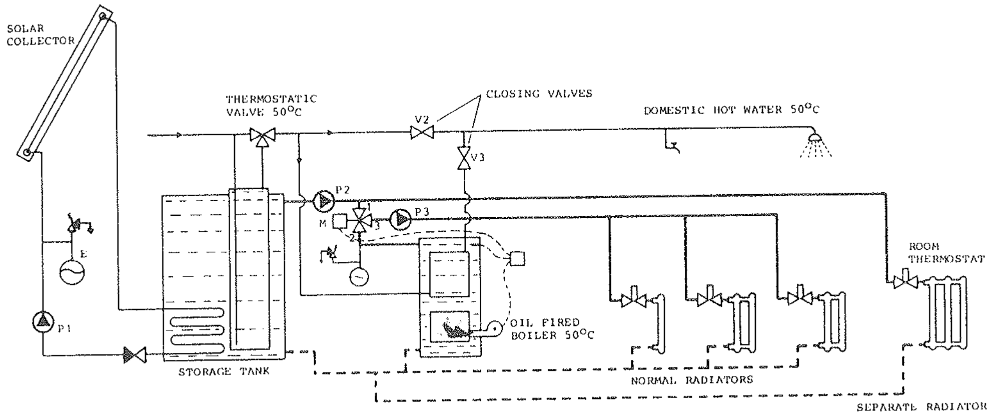


Fig. 5.24 System diagram, 1st design

Solar energy for space heating is now delivered via a separate heat exchanger (radiator), situated in the main room (normally an open-plan kitchen/dining room/living room). The solar radiator has preference to space heating in this room.

Solar energy can now be utilized down to a storage temperature of 20°C, and the backup heating system does not interfere with system performance.

During the summertime and during periods in autumn and spring with ample solar energy available, the boiler is shut off manually. The motorized valve M then automatically changes position so that port 1-3 is open instead of port 2-3. Solar energy is then supplied to all the radiators in the house. The two closing valves V2 and V3 have to be turned manually so that domestic hot water flows directly from the store to the taps.

In order to decrease heat losses from the store, all the necessary components are gathered in an insulated cabinet, as in the final design (see section 5.5.4).

Further revision of system design

The first design shows solutions to some of the problems of the previous designs. One major feature needs future modifications.

However, the users have to watch the temperature of the storage tank very carefully in order to have the boiler closed down for as many days of the year as possible, in order to minimize the idle losses. They have to interfere in the system operation manually by turning the boiler off/on quite often and simultaneously by operating the valves V2 and V3. The users will hardly be able to judge if a given storage temperature is adequate to cover their immediate request for space heating. The possibilities for wrong or non-optimal operation of the system certainly exist, and the potential savings may not be achieved in practice.

Final design

The final design is discussed in more detail in section 5.4. In order to finalize the description of the logical system development, the final design will be presented very briefly.

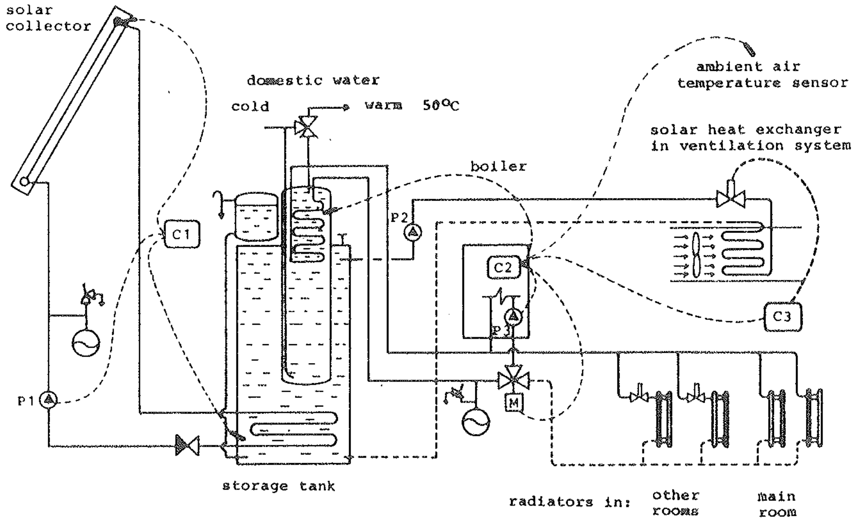


Fig. 5.25 System diagram, final design

The main advantage of the final design over the previous design is that the auxiliary boiler is automatically shut off if there is neither a demand for auxiliary space heating nor for DHW postheating.

Solar energy for space heating is delivered via a separate water to air heat exchanger which is inserted in the small ventilation system.

Domestic hot water preheating and postheating is now totally covered via the storage tank. This means that the auxiliary boiler should not have a DHW tank included, and in the actual case the boiler chosen is of a very light type (49 kg) which is mounted on a wall.

5.11 COMPONENTS: INITIAL SELECTION AND REVISIONS

5.11.1 Introduction

The main concerns re. component choice were the collector and storage tank. The other components, such as pumps and valves, etc. were selected on the basis of previous experience.

5.11.2 Initial design and basis for selection

Collector

Initially, it was envisaged to use standard collector elements, typically of 1 · 2 m^2, as shown in appendix 5.2. The final design consists of partly prefabricated elements, each of 2 · 5 m^2. A reduction in costs can be achieved in this way, partly because of the area per house, minimum 10 m^2, and partly because of the large number of identical 10 m^2 units that can be fabricated, given that 50 - 100 houses are to have identical solar systems. The reduction in costs for a 10 m^2 collector installed was, in the actual case study, calculated to be 24%, resulting in a collector price of 1200 dcrs/m^2 (or 150 ECU/m^2).

Storage System

The initial storage design and the final design are almost the same, see fig. 5.13 in section 5.5.4. The main difference is that the immersed DHW tank is extended above the top of the main store, in order to make post-heating of DHW an integral part of the storage system. In the actual case, the DHW tank can be allowed to penetrate up into the roof space since this is not occupied.

If this storage design concept should be used in houses with occupied top storey, the total height of the heat storage system would have to be limited to the headroom of one storey, i.e. 2.3 m. This would not cause major problems, since the dimensions of the main store can easily be adjusted in order to maintain a given volume of on average 500 - 750 l.

5.12 PERFORMANCE: A COMPARISON OF ORIGINAL AND FINAL PERFORMANCE

The main characteristics of the system affecting system performance were not changed from original to final design.

5.12.1 Introduction

The thermal performance of the collector has not changed from original to final design. The present collector is an integrated design, and the thermal performance is assumed to be similar to the performance of a 1 · 2 m^2 collector element with the same glazing, absorber and insulation. The performance predictions are based on the 1981 version of the collector, (see appendix 5.2). A new version of the collector with a redesigned absorber and with low-iron glazing was tested recently, giving improved performance, see appendix 5.3.

The present version of the SVS simulation model does not allow for detailed evaluation of storage tank performance (stratification) and the detailed performance of the separate solar heat exchanger. It has therefore not been possible to quantify the extra benefit in performance of the final design with a water-to-air heat exchanger, where the inlet air temperature is lower than the room temperature.

5.12.2 Comparison of initial and final design performance.

The performance of the final design, 10 m^2, has been found to be 255 kWh/m^2 collector. If the collector characteristics of the 83 collector is used, the performance is increased to 271 kWh/m^2. It should be noted that the final run with the EMGP2 model by Arnold Debosscher of Leuven University was done using the improved version of the collector. The EMGP2 predicted a performance of 280 kWh/m^2 collector, which is in accordance with the prediction made by using the SVS simulation code.

It should finally be noted that the effect of changing the house towards better utilization of passive solar energy has been investigated. The actual house is a thermally light house with only 3.9 m^2 window toward south.

The influence on the annual heating load of moving windows from the eastern and the western facade to the southern facade has been investigated. Furthermore the calculations have also been performed with a version of the house which is thermally heavy.

The layout of the case study house is discussed in section 5.2. From figure 5.1 of this section, it can be seen that the window of the living room facing east could easily be moved to the south facade of the house. Similarly, the window of the bedroom towards south-west could easily be moved from the western facade to the southern facade. The aperture area of the eastern window is 1.40 m^2, whereas the aperture area of the western window is 0.90 m^2.

The thermally heavy house is one with hard-burned bricks on the floor instead of carpets. In both cases, there is a 100 mm concrete floor slab. Furthermore, the thermally heavy version of the house has inner walls made of 110 mm brickwork instead of a wood frame structure with 12 mm chip board.

The heating load of the house with variations in window orientation and thermal capacity has been modelled using the BA4-programme. The output of each computer simulation is the heating load on an hourly basis. These heating load data are then used as input data to a computer simulation of the performance of the solar heating system.

COMPUTER RUN	COLLECTOR AREA	HOUSE	HEATING LOAD kWh/m2	OUTPUT OF SOLAR HEATING SYSTEM kWh/m2	SOLAR FRACTION %
1	10	ORIGINAL (Case Study House)	7360	283	27
	20			190	36
2	10	ONE WINDOW MOVED to south facade	7280	283	27
	20	LIGHT HOUSE		190	36
3	10	LIKE 2	6830	262	27
	20	HEAVY HOUSE		174	35
4	10	TWO WINDOWS MOVED to south facade	7180	283	28
	20	LIGHT HOUSE		190	37
5	10	LIKE 4	6680	261	27
	20	HEAVY HOUSE		173	35

Fig. 5.26 Heating load and solar fraction for varying layout of the house.

The performance of the solar heating system is in each case shown for two sizes of the collector, 10 m^2 and 20 m^2. In both cases the DHW load is 200 l/day. The main characteristics of the solar heating system can be seen in figure 5.15 of section 5.6.3, only the collector efficiency is slightly different. The performance of the 10 m^2 solar heating system on the reference house is 283 kWh/m^2, whereas the performance with the solar collector which was finally chosen (see section 5.6.3) is 285 kWh/m^2.

In run no. 2, the western window has been moved to the south facade, whereas in run 4 both the eastern and the western window have been moved to the south facade. Moving windows to the south facade gives the expected result, e.g. the heating load is decreased. It is interesting, however, that given the thermally light version of the house, this decrease in heating load has no influence on the performance of the active solar system. Only in the case of a thermally heavy house, the decrease in heating load leads to a decrease in performance of the solar heating system.

The decrease in performance of the 10 m^2 solar heating system going from the original case study house to a thermally heavy house with a relatively large south facing window area is (283 - 261) kWh/m^2 = 22 kWh/m^2, or 8%. Changing the house towards a passive solar house has not a very big influence on the performance of the active solar system. It should be noted that these results are not necessarily valid for any combination of passive and active solar heating designs.

5.13 COST EFFECTIVENESS: A COMPARISON OF ORIGINAL AND FINAL DESIGNS

5.13.1 Introduction

The difference between initial and final design primarily concerns the system control strategy. In the first design, the user had to interfere in the system operation in order to gain maximum performance. The system would then probably not perform "ideally", but the decrease in performance due to this cannot be assessed.

5.13.2 Comparison of initial and final cost-effectiveness.

It can be argued that the cost-effectiveness, going from the original design (see. fig. 5.24) to the final design (see. fig. 5.25), has not changed changed significantly. The main difference between the two designs is that the possibility of actually achieving the potential benefits is greater with the final design. The final design does not presuppose any interference from the user, and the auxiliary boiler shuts down automatically when not needed.

5.14 CONCLUSIONS

5.14.1 Principle lessons from the design exercise

The main conclusion is that even in a low-energy house a combined solar energy system may show a cost-effectiveness ratio which shows major improvements over previous systems (5.7).

The load for space heating and DHW amounts to only 9900 kWh/annum, yet the proposed 10 m^2 solar system has a performance of 255 kWh/m^2, and the system has a performance to a cost ratio of .74 kWh/annum per invested ECU. The solar heating system covers 26% og th annual load for space heating and domestic hot water.

The conclusions from a technical point of view can be summarized as follows:

- It is a major advantage to combine the heat storage tank with domestic hot water preheating and postheating in one unit.

- The use of a separate heat exchanger to supply solar energy for space heating is cheap and uncomplicated.

- The backup heating boiler should give preference to solar energy. In order to save the idle losses, the boiler should work only when there is a heating demand. This was achieved in the final design.

5.14.2 Future technical improvements

The basic system design concept: integrated storage tank and a separate solar heat exchanger for space heating, is regarded as a very well-adapted design. Future technical improvements should be concentrated around:

1. The collector:

The collector might be developed further so that a large, totally prefabricated collector unit is available.

2. The system/storage tank

The primary circuit could be developed to a drain-down system connected to an open storage tank made of anti-corrosive material (i.e. plastic or rubber or stainless steel). The primary circuit heat exchanger and the purchase of glycol would then be eliminated. There is also scope for reducing the cost of the total system. Furthermore, the performance may be improved a little.

The improvements indicated, along with industrial development of the system, could lead to a design consisting of a few, wholly prefabricated components: Collector elements each of 5-10 m^2, storage unit with all components installed, and the solar space heating heat exchanger. The working hours on the building site would be substantially decreased. Findings from other building and installation processes indicate that this leads to reduction in the total costs of the system.

5.14.3 Future cost reductions and cost-effectiveness

The cost for the solar heating system may be decreased in three ways:

1. Further development of design
2. Industrial development and adaptation of the design
3. Mass production

Mass production of the present design would give a cost reduction of 20-25%, (see section 5.7). The possibilities for cost reduction as a result of further development of the design and industrial adaptation can obviously not be assessed very precisely. A reasonably conservative judgement would nevertheless indicate that the total costs could be diminished by 50%, including the benefits of mass production.

The performance level of the system could be improved via better collectors and via an improved system/storage design.

It is difficult to judge whether evacuated tubular collectors can compete with flat-plate collectors in the future for low-temperature application. Further development of the flat-plate collector will not improve performance drastically, but together with an improved system design, an improved performance of at least 25% must be possible.

The performance/cost ratio of the present design is 0.74 kWh/Invested ECU. Given a cost reduction of 50% and a performance improvement of 25%, the performance/cost ratio would rise to almost 2.0 kWh/invested ECU. Further development of this type of solar system should be judged based on a cost-effectiveness ratio in that region.

REFERENCES:

5.1 Solar systems for space heating - in Danish (Solvarmeanlæg til rumopvarmning).
Thermal Insulation Laboratory, report no. 112, August 1981.
Sv. E. Mikkelsen, L.S. Jørgensen.

5.2 Solar Space Heating: An Analysis of Design and Performance Data from 33 systems.
Commission of the European Communities.
Performance Monitoring Group.
Editors: R. Godoy, D. Turrent, R. Ferraro.
EUR 8004

5.3 Program BA4 for calculation of room temperatures and heating and cooling loads - Users Guide.
Thermal Insulation Laboratory, 1979
H. Lund

5.4 SBI Report 135 - Meteorological data for HVAC and energy, Danish Test Reference Year TRY.
Danish Building Research Institute, 1982

5.5 Description of simulation codes and monthly tables.
CEC Solar Energy R&D Programme, Project A.
Modelling and Simulation part.
June 1979

5.6 Building Regulations 77.
National Building Agency
Ministry of Housing, Copenhagen

5.7 Performance Monitoring of Solar Heating
Systems in Dwellings - Executive
Summary and REcommendations
Commission of the European Communities
December 1981

5.8 Solar system Case Study
Final Design DHW
Northern European Design Group
June 1983
Commission of the European Communities

APPENDIX 5.1

Thermal insulation of Danish houses

Since World War II it has been common to insulate the new-built Danish houses. Until the middle of the fifties only the roofs were insulated and with around 25 mm of mineral wool. Exterior walls had an uninsulated cavity. Some windows were single-glazed and some double-glazed.

From the beginning of the sixties the cavities in the exterior walls were insulated (50-75 mm) and the roofs were insulated with 75-100 mm. All windows were now equipped with double-glazing.

The next major improvement in insulation level was caused by the "oil crisis" in the seventies. The building code of 1977 (mandatory from 1979 as regards insulation regulations) increased the required insulation level significantly as compared to the previous code. The change in the building industry was quite smooth since the actual insulation level up through the period 1974-1977 approached the level that became mandatory in 1979. The new building code of 1982 is as regards insulation levels unchanged. The required insulation levels of the building parts are:

	K-value $W/m^2 {}^oC$
External walls, total weight exceeding 100 kg/m^2	0.40
External walls, total weight less than 100 kg/m^2	0.30
Solid ground floor	0.30
Floor over open air	0.20
Ceiling and roof	0.20
External doors	2.00
Windows	2.90

The window area is normally not allowed to exceed 15% of the gross floor area of the house. You may nevertheless deviate from one or more demands if the heat loss coefficient of the house as a total does not exceed the heat loss coefficient of a house of the same geometry, but insulated strictly according to the values mentioned above. You may for instance be allowed to have window areas larger than 15% if this is compensated by triple glazing in the windows (which in any case is becoming quite popular) or better insulation level of the other building parts.

Generally, the insulation level of the new houses built is somewhat better than stated in the building code. Typically, the range of at the actual heat loss coefficient would be from 100% down to 70% as compared to the building code.

APPENDIX 5.2

Datasheet for collector used in the case study

DATASHEET ON SOLAR COLLECTOR EFFICIENCY	Date: 05-05-1983
Manufacturer: DANSK SOLVARME K/S, KABELVEJ 5, V. HASSING STRAND, 9310 VODSKOV	Type: KP V
Test Laboratory: THERMAL INSULATION LABORATORY, TECHNICAL UNIVERSITY OF DENMARK	Solar collector id-no.: 174

Outside dim: 2,04 x 1,04 x 0,10 m

Weight: 63 kg

Transparent area: 1,93 m^2

Number and type of glazing: Single 4 mm glass

Absorber panel:

Type: channel plate

Material: stainless steel

Thickness: top/bottom: 0,6 mm/0,6 mm

Channelsystem: lengthwise with traversing connections

Headers: integrated in the absorber

Surface treatment: selective foil, MAXORB

Insulation, back: 60 mm mineral wool

Insulation, edge: 25 mm wood and aluminium foil

Solar collector frame: the frame is made of a aluminium profile with the dimensions 30 x 100 x 3 mm

Tightening: sealing strip between glass and frame

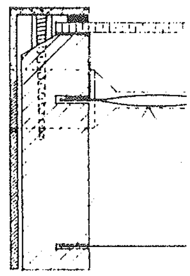
Recommended maximum pressure: 250 kPa

Pressure loss: 1,8 kPa at a fluid flow rate of 0,038 kg/s (50% propylene glycol)

Connection: can be made to the two outsticking sockets in the upper part of the long sides

Mounting: The solar collector can be mounted on the roof or be integrated in the roof as a flashing system can be delivered. The fastening can be made with fittings to the frame or squarehead screws from the back.

Section:

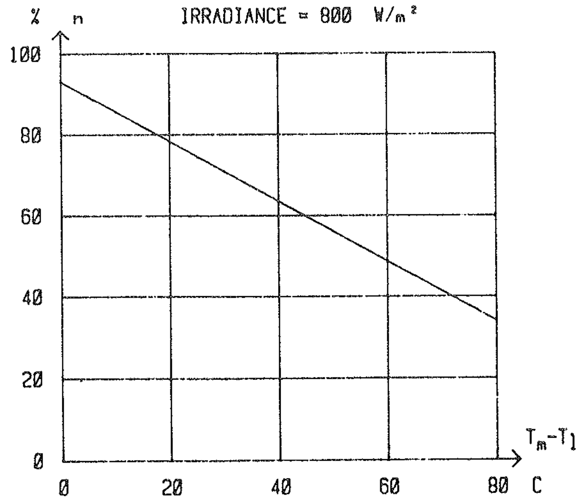


Efficiency expression under the following conditions:

Tilt 45°, fluid flow rate 0,038 kg/s
50% propylene glycol, wind speed 5 m/s

$$\eta = 0,93 - 5,9 \frac{T_m - T_1}{E} - 0,000 \frac{(T_m - T_1)^2}{E}$$

where η = efficiency
T_m = mean fluid temperature
T_1 = air temperature
E = irradiance



Comments to the test:
When stagnation testing the solar collector the absorber plate bulged at the center of the lower third.

APPENDIX 5.3

Datasheet for 1983 prototype collector

DATASHEET ON SOLAR COLLECTOR EFFICIENCY	Date: 1982-07-30
Manufacturer: DANSK SOLVARME K/S, KABELVEJ 5, V. HASSING STRAND, 9310 VODSKOV	Type: KP IV R.S.
Test Laboratory: THERMAL INSULATION LABORATORY, TECHNICAL UNIVERSITY OF DENMARK	Solar collector id-no.: 144

Outside dim: 2,04 x 1,04 x 0,09 m

Weight: 76 kg

Transparent area: 1,93 m^2

Number and type of glazing: single, 4 mm glass

Absorber panel:

Type: channel plate

Material: stainless steel

Thickness: top/bottom: 0,9 mm/0,6 mm

Channelsystem: lengthwise with traversing connections

Headers: integrated in the absorber

Surface treatment: selective foil, MAXORB

Insulation, back: 50 mm mineral wool

Insulation, edge: 27 mm wood and aluminium foil

Solar collector frame: the frame is made of a galvanized steel profile with the dimensions 30 x 75 x 3 mm

Tightening: sealing strip between glass and frame

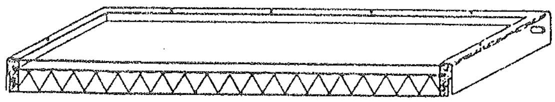
Recommended maximum pressure: 250 kPa

Pressure loss: 2,3 kPa at a fluid flow rate of 0,038 kg/s (50% propylene glycol)

Connection: can be made to the two out-sticking sockets in the upper part of the long sides

Mounting: The solar collector can be mounted on the roof or be integrated in the roof as a flashing system can be delivered. The fastening can be made with fittings or square-head screws from the back.

Section:

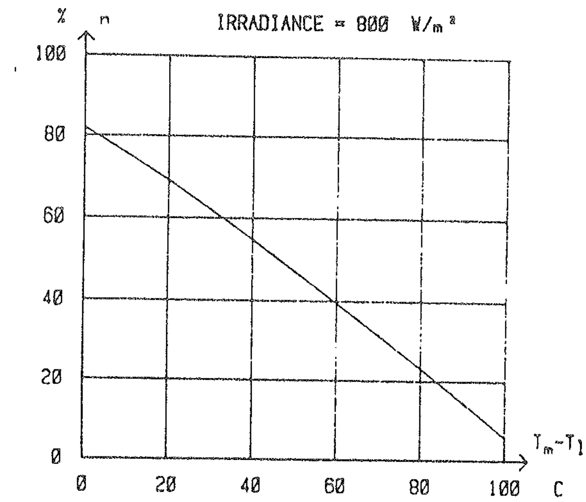


Efficiency expression under the following conditions:

Tilt 45°, fluid flow rate 0,038 kg/s
50% propylene glycol, wind speed 5 m/s

$$\eta = 0,82 - 5,0\frac{T_m - T_l}{E} - 0,011\frac{(T_m - T_l)^2}{E}$$

where η = efficiency
T_m = mean fluid temperature
T_l = air temperature
E = irradiance



Comments to the test:
None