IEA 14 ADVANCED SOLAR ENERGY SYSTEMS

INTERNATIONAL ENERGY AGENCY
Solar Heating & Cooling Programme

LARGE SOLAR ENERGY SYSTEMS

A Report of Task 14

LARGE SYSTEMS WORKING GROUP

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IEA-SOLAR HEATING AND COOLING PROGRAM - DESCRIPTION

The International Energy Agency, headquartered in Paris, was founded in November 1974 as an autonomous body within the framework of the Organization for Economic Cooperation and Development (OECD) to coordinate the energy policies of its members. The twenty-three member countries seek to create the conditions in which the energy sectors of their economies can make the fullest possible contribution to sustainable economic development and the well-being of their people and the environment.

The policy goals of the IEA include diversity, efficiency and flexibility within the energy sector, the ability to respond promptly and flexibly to energy emergencies, the environmentally sustainable provision and use of energy, more environmentally-acceptable energy sources, improved energy efficiency, research, development and market deployment of new and improved energy technologies, and cooperation among all energy market participants.

These goals are addressed in part through a program of collaboration in the research, development and demonstration of new energy technologies consisting of about 40 Implementing Agreements. The IEA's R&D activities are headed by the Committee on Energy Research and Technology (CERT) which is supported by a small Secretariat staff in Paris. In addition, four Working Parties (in Conservation, Fossil Fuels, Renewable Energy and Fusion) are charged with monitoring the various collaborative agreements, identifying new areas for cooperation and advising the CERT on policy matters.

IEA SOLAR HEATING AND COOLING PROGRAMME

The Solar Heating and Cooling Programme was one of the first collaborative R&D agreements to be established within the IEA, and , since 1977, its Participants have been conducting a variety of joint projects in active solar, passive solar and photovoltaic technologies, primarily for building applications. The twenty members are:

Australia	France	Spain
Austria	Germany	Sweden
Belgium	Italy	Switzerland
Canada	Japan	Turkey
Denmark	The Netherlands	United Kingdom
European Commission	New Zealand	United States
Finland	Norway	

A total of twenty two projects or "Tasks" have been undertaken since the beginning of the Solar Heating and Cooling Program. The overall program is monitored by an Executive Committee consisting of one representative from each of the member countries. The leadership and management of the individual Tasks are the responsibility of Operating Agents. These Tasks and their respective Operating Agents are:

Task 1* :   Investigation of the Performance of Solar Heating and Cooling Systems - Denmark
Task 2* :   Coordination of Research and Development on Solar Heating and Cooling - Japan
Task 3* :   Performance Testing of Solar Collectors - Germany/United Kingdom
Task 4* :   Development of an Insolation Handbook and Instrumentation Package - United States
Task 5* :   Use of Existing Meteorological Information for Solar Energy Application - Sweden
Task 6* :   Solar Systems Using Evacuated Collectors - United States
Task 7* :   Central Solar Heating Plants with Seasonal Storage - Sweden
Task 8* :   Passive and Hybrid Solar Low Energy Buildings - United States
Task 9* :   Solar Radiation and Pyranometry Studies - Canada/Germany
Task 10* :   Material Research and Development - Japan
Task 11* :   Passive and Hybrid Solar Commercial Buildings - Switzerland
Task 12* :   Building Energy Analysis and Design Tools for Solar Applications - United States
Task 13 :   Advanced Solar Low Energy Buildings - Norway
Task 14 :   Advanced Active Solar Systems - Canada
Task 15 :   Not initiated
Task 16 :   Photovoltaics in Buildings - Germany
Task 17 :   Measuring and Modeling Spectral Radiation - Germany
Task 18 :   Advanced Glazing Materials - United Kingdom
Task 19 :   Solar Air Systems - Switzerland
Task 20 :   Solar Energy in Building Renovation - Sweden
Task 21 :   Daylighting in Buildings - Denmark
Task 22 :   Building Energy analysis tools-USA
* Completed

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DESCRIPTION OF IEA SHCP - TASK 14 - ADVANCED ACTIVE SOLAR SYSTEMS

Task 14 was initiated to advance the state-of-the-art in active solar energy systems. Many features developed during the few years before the start of the Task, when used alone or in combination, had the potential to significantly improve the performance of these systems. It was the objective of Task 14 to analyze, design, evaluate and, in some cases, construct and monitor a number of different systems incorporating one or more of these features.

The work of the Task was divided into three Working Groups, based on the type of systems studied, and one Sub Task dealing with dynamic testing. The goal of the Working Groups was to facilitate interaction between participants with similar projects. Participants were able to identify and address issues of common interest, exchange knowledge and experience and coordinate collaborative activities.

Domestic Hot Water Systems - Working Group   The focus of this Working Group was the development of advanced DHW systems using the "low flow" concept. Participating countries contributed expertise related to different system components. The collaborative work in the Task brought this expertise together to allow participants from each country to design systems which show a significant cost/performance improvement (as high as 45%) over systems on the market in their respective countries when the Task began.

Air Systems - Working Group Task work concentrated on further development of a commercially available concept for the preheating of ventilation air in industrial and commercial buildings. This concept is a specially designed cladding system to capture the air heated by solar radiation on the south wall of a building. Four projects, two in Canada, one in the USA and one in Germany, were constructed using a perforated version of the wall. The German project adapted the concept to preheat combustion air for a district heating plant. The practical work of these projects was complemented by theoretical work conducted at the University of Waterloo in Canada and the National Renewable Energy Laboratory (NREL) in the United States. Task work demonstrated that the cost/performance of the perforated wall is over 35% greater than earlier versions of the design.

Large Systems - Working Group   The Task also examined large scale heating systems involving temperatures under 200°C. Five large systems were studied. They were all very different but each represented important applications of active solar systems. District heating, the subject of the Swedish project, can be used in most IEA member countries to provide space and water heating for communities. The German project also involved district heating but with no storage. A tulip bulb drying installation in The Netherlands explored the staggered charging and discharging of long term storage, a strategy which may find many uses, especially in agricultural applications. Solar desalination, the subject of the Spanish project, has wide application in water starved areas of the world and could represent a major export opportunity for IEA countries. Industrial process heat was represented by a project in Switzerland. Since virtually all large systems are custom designed, cost/performance improvements for this Group was not a meaningful measure of achievement. Documentation of lessons teamed is the most important product of the work. Three of the final projects are reported. Two projects added valuable information. Their lessons learned are included in the report. One project was already finished. This information is included in the report

Dynamic System Testing Sub Task   The work of this Sub Task within Task 14 provided a continuation of work completed earlier by the IEA Dynamic Systems Testing Group. That Group established that dynamic fitting was a suitable tool in processing laboratory tests and in-situ monitoring of solar domestic hot water systems. The objective of the new sub-task in Task 14 is the continued development and evaluation of dynamic testing of solar energy systems, subsystems and components for prediction of long term system performance from short term tests.

Task 14 activities began in 1989 and were completed in 1995.
The following countries participated in this Task:

Canada	The Netherlands	Switzerland
Denmark	Spain	United States
Germany	Sweden	

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ABSTRACT

Within Task 14 (Advanced Solar Systems) of the International Energy Agency Solar Heating and Cooling programme a working group was established dealing with large advanced solar energy systems (the Large Systems Working group).

The goal of this working group was to generate a common base of experience for the design and construction of advanced large solar systems. The large systems group initially had five participants. Three participants succeeded in carrying out the complete process; from design through construction and monitoring towards evaluation. This report describes the three projects in Germany, Sweden and The Netherlands.

Since it is hard to compare these projects, the common base was looked for by investigating the lessons learned and suggesting general guidelines. The contributors feel that this information is most valuable for future projects.

Sweden built a Central Solar Heating Plant with Diurnal Storage in Falkenberg. The CSHPDS includes a 5500 m^2 ground mounted flatplate collectors with an extra teflon layer as convection barrier, and an insulated 1100 m3 steel storage tank. The system is connected to the heating plant of the district heating system of a small town. Over three years the annual average of solar heat delivered to the district heating network was 5.2 TJ, which is a solar fraction of about 6%.

At Falkenberg the investment cost per yearly GJ were reduced by 20% compared to the similar Nykvarn I system. The return temperature of the DH network was rather high due to consumer installations not designed for low return temperatures. A considerable decrease in the DH return temperature was achieved by revamping and adjusting the consumer substations and local networks.

In Gottingen, Germany, an old building housing the co-generation power plant of the large district-heating had been renovated using two solar systems: 783 m^2 of roof integrated flat plate collectors, equipped with a Hostaflon foil convection barrier, connected directly to the district heating network; 340 m^2 transpired "Solar Wall" air collectors to preheat the combustion air of the power plant gas burners. Three years of research and monitoring have shown that the collectors were performing very close to their calculated efficiency characteristics; however, rather high operating temperatures reduced the collector output to values lower than predicted. Problems in changing the district heating operating conditions had been underestimated and could not be met according to the initial schedule. Experience gained through the collaborative task work has helped to convince the town utility company to fulfill its original commitment with a complete renovation of the network.

In Lisse, The Netherlands, a large solar system(1200 m^2) with seasonal storage (1000 m) for drying bulbs has been constructed. The solar contribution in this system should be around 35 % due to the large storage. The waterbased seasonal storage system has two cycles per year, one for the drying process and the other for the conditioning of the bulbs. An additional innovation is the combination of the underground storage tank and the building put on top. Due to the Dutch ground and groundwater conditions this was a very challenging construction; the storage tank is more or less floating in the groundwater and pilingworks for the building were constructed through the storage. Construction problems and failures delayed the completion of the project considerably. Finally, at the end of 1994 the complete system was put into operation. During 1995 the system functioned well. The energy analysis shows a large discrepancy between the calculated energy design data and the measured ones. Due to the hot summer, the drying process needed less energy, therefore the storage tank achieved and maintained a high average temperature which led to larger losses and lower solar contributions. The solar fraction was much higher than designed. An other year of measuring is necessary for more definitive conclusions.

Documentation of the lessons learned is the most important product of this international research. Among others, the following observations are concluded. The long planning period for realising these projects makes it important to have clear goals for all parties involved in the project.

Further integration and improved communication between the "conventional" part of the system and "slar" part of the system is recommended.

International collaboration contributes significantly (e.g. teflon barrier, return temperature district heating) to enhancement of the knowledge and experience for these type of systems.

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EXECUTIVE SUMMARY

Task 14 was initiated to advance the state-of-the-art in active solar energy systems. Many features developed during the few years before the start of the Task, when used alone or in combination, had the potential to significantly improve the performance of these systems. It was the objective of Task 14 to analyze, design, evaluate and, in some cases, construct and monitor a number of different systems incorporating one or more of these features.

The large systems working group within the Task examined large scale heating systems involving temperatures under 200°C. Five large systems were studied. This report covers three of those systems. Two other projects, Solar desalination in Spain, and an Industrial process heat project in Switzerland, are reported separately .

These projects were essentially complete before the Task began.

The three reported projects were all very different but each represent important applications of active solar systems. District heating, the subject of the Swedish project, can be used in most IEA member countries to provide space and water heating for communities. The German project also involved district heating but had contrary to the Swedish project, no storage included. A tulip bulb drying installation in The Netherlands explored the staggered charging and discharging of long term storage, a strategy which may find many uses, especially in agricultural applications. Since virtually all large systems are custom designed, cost/performance improvements for this Group was still an important issue, but not top priority. Instead documentation of lessons learned is the most important product of the work. In the following table the characteristic parameters of the three systems are summarized.

Aspect	FALKENBERG	GÖTTINGEN	LISSE
Collector type/area	flatplate, teflon convection barrier 5500 m²	flatplate, hostaflon convection barrier 800 m²	flatplate, 40% teflon convection barrier 1050 m²
Storage	1100 m³ steeltank	no storage	1000 m³ underground storage
Application	District Heating	District Heating	Bulb drying process heat
Design Heat consumption Solar contribution Solar cost	DH: 100 TJ Solar: 5.2 TJ Costs: 31 US$/GJ	DH: 360 TJ Solar: 1 TJ Costs: 36 US$/GJ	Process: 5.7 TJ Solar: 1.7 TJ Costs: 29 US$/GJ
remarks & observations	- high return temperature DH - corrosion storage tank	- lowering high return temperature DH difficult	- construction underground storage - lower process heat consumption
lessons learned	- lowering the return temperature district heating system - application of teflon films as convection barrier - construction of underground heatstorage		

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Sweden-Falkenberg

An experimental Central Solar Heating Plant with Diurnal Storage (CSHPDS) is connected to the district heating (DH) plant of the small town of Falkenberg, Sweden. The CSHPDS includes a ground-mounted flat plate solar collector array of 5500 m^2 and an insulated steel tank containing 1100 m^3 of water. The two are connected by a 720 m heat distribution pipe. The heating plant comprises two wood chip boilers and two natural gas boilers.

The district heating system and the CSHPDS are owned and operated by the local utility company Falkenberg Energi AB. The yearly heat production is approximately 100 TJ, which is delivered to 73 substations connected to the network.

The solar heating plant performs well. It has been in operation and monitored since January 1990. During the three years 1990, 1991, and 1992 the yearly average solar heat delivered to the district heating network was 5.2 TJ (1.01 GJ/m^2), which makes up six per cent of the total heat delivered. During a few days in the summer the solar heating plant carries the total load. The monthly solar fraction exhibited its highest value, sixty per cent in July 1991.

TeknoTerm AB built the solar heating plant as a turn-key project. The collector used is the 12 m^2 TeknoTerm HT, which is basically of the same design as the Swedish Nykvarn I plant, which was erected in 1985. At that time, the Nykvarn I plant manifested a substantial decrease in cost of solar energy compared to earlier plants of this type.

At Falkenberg, the investment cost per yearly GJ from the CSHPDS was 31 US$ (Price level of February, 1989. 1 USD = 7 SEK). This was a twenty per cent reduction compared the CSHPDS of Nykvarn I. A comparison based on the collector array alone shows an equal large cost reduction.

The return temperature of the DH network at Falkenberg was rather high because customer installations were not designed for low return temperatures. In order to improve the working condition of the solar plant, half of the customer installations were modified. A considerable decrease in the DH return temperature was achieved by modifying the customer substations and local networks. The investment cost to lower the return temperature was 9 US$ per yearly GJ (February 1989, 1 USD = 7.0 SEK).

Germany-Gottingen

The old building housing the co-generation power plant of the large district-heating of the town of Göttingen had been renovated using two solar systems: 783 m^2 of roof integrated flat plate collectors, equipped with a Hostaflon foil convection barrier, connected directly to the district heating network and 340 m^2 transpired "Solar Wall" air collectors to preheat the combustion air of the power plant gas burners. This report deals with DH system. The solar collectors are directly coupled to the district heating system. The annual heat demand in the main DH network is approximately 360.000 GJ. The summer load between May and September is 15% of the total annual load. The return temperature of the district heating system during the year differs between 65 °C and 75 °C depending on the ambient temperature and the combined heat and power mode.

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It was decided to connect the solar system to the main DH network. To improve the practically of the system Stadtwerke Göttingen, the local utility, made a commitment to lower the network return temperature to approximately 40 °C. Based on this temperature level, the solar contribution was calculated to be 1026 GJ. The solar costs were calculated on 36 US$/GJ.

Three years of research and monitoring have shown in detailed investigations that the collectors were performing very close to their efficiency characteristics. No signs of degradation of the collectors were observed. However, the collector array output is substantially lower than calculated during the design period, because the actual operating temperature of the DH load of 70 °C is still much higher than the 40 °C scheduled during the design phase.

Because problems in changing the district heating operating conditions had been underestimated, the optimal operation conditions could not be met according to the initial schedule; thus, the measured solar output is close to 50% of the values planned

Experience gained through the collaborative task work has substantially contributed to convince the town utility company to fulfill its original commitment within a complete renovation of the network.

Netherlands-Lisse
Beginning in 1990 a project on bulb drying in Lisse was initiated. The project started with a feasibility study. The heat demand for this project is typical for these type of processes. After harvest, the bulbs are dried in order to prevent for infections. The drying takes place in the summer with slightly heated ambient air.

Next, the bulbs undergo an artificial autumn and winter cycle through conditioning. Herewith the time of flowering of the bulbs is established. Although the heat demand for this process is high, the temperature levels are low.

The future yearly heating load is predicted to be about 5.7 TJ. A comparison of the price/performance ratios of several proposed systems was carried out. A fluid based system with a seasonal storage, which is charged/discharged twice a year, turned out to be considerably more cost-effective than alternatives and is more innovative and interesting. For that reason fitted in the IEA task 14 framework.

Based on a total yearly heat demand of about 5.7 GJ and a solar contribution of 1.77 GJ, the solar costs were calculated on 28.8 US$/GJ (without subsidies).

The construction work for the project started beginning 1993. Due to the special requirements of the storage, as well as the specific soil conditions and groundwater level, standard construction techniques could not be used for the storage tank.

The 1000 m^3 storage had to meet the following requirements: temperature resistance 25°- 80° C, the top of the storage to be used as factory-floor, durable insulation on all sites of the store and no water leakages in-or out the storage. Special attention for the construction was caused by the fact that the groundwater level will vary between 0.6 and 1.0 m[1] below ground level. This condition will make the storage a floating vessel during construction and/or maintenance situations, with an actual danger of rising. Apart from this, the requirement that the top of the storage should be used as the factory floor, a foundation using concrete pilings through the storage tank was unavoidable.

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Finally the storage tank was constructed with polystyrene on the top and the bottom. The bottom of the store is ballasted with concrete to avoid floating of the polystyrene insulation. The store walls are insulated with foamglass with a special coating on top to prevent etching.

The system was finished and came into operation at the end of 1994. The first monitoring year was 1995. Results show a much lower energy demand (917 GJ) of the drying plant then predicted. This resulted in 1995 in a solar contribution of 64% (696 GJ) to the drying wall.

Due to the long project development time the original system and process criteria have changed. This causes other uses of the system than originally foreseen. For instance the water to air heaters in the drying wall probably have a lower heat transfer coefficient than designed. During the first months of 1996 further analysis will take place, in order to further optimize the thermal performance of this system.

Conclusions and observations.

The work of this group leads to a number of guidelines and recommendations for future builders of large solar systems. For detailed information see the final report chapter 6.

- Thoroughly review the project details and load parameters. Confirm the information supplied by third parties by yourself.
- Ensure that the requirements of financing parties are compatible with the general objectives of the project.
- Confirm new technical solutions on a small scale, before applying into practise
- Ensure that the system is operating as defined. Among other things, this means that the operators are correctly instructed.

Specific technical details in the report include teflon as convection barrier in collectors , the design and construction of the underground 1000 m ^{3} storage and strategies to lower the return temperature of district heating network.

The overall conclusions are summarized as follows:

- The design and construction of large solar energy systems is a complex matter. Solar energy installations have strong interrelations and are heavily influenced by installations techniques and temperature levels in the conventional part of the installation.
- At the interface between the solar and conventional installations many improvements (price and performance) can be made. Therefore an integral design approach is highly recommended.
- From project initiation to completion and evaluation good co-operation with the user is extremely important.
- Large systems should have a basic monitoring system, for commissioning and evaluation purposes.
- International collaboration is very valuable for exchange of know-how on specific topics considering solar components and system design.
- A thorough integral design process is required to avoid the solar system being blamed for a malfunctioning conventional system.

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1. INTRODUCTION

The large systems group of Task 14 (LSG) was established in the earlier stage of the Task. The LSG committed itself to generate a common base for the design and construction of large solar systems. Although large systems all seem to be unique in design and construction, the common base was looked for by investigating the lessons learned and general guidelines for those who want to design and build similar large solar projects.

All systems adopted in this Task can be considered advanced in their own kind. The exchange of ideas within the LSG enabled the engineers/designers of these plants to evaluate the first designs and to use a rich source of available international knowledge. The experience of the LSG, working with large systems, is expressed in this report.

Participating countries in the LSG were: Spain, Switzerland, Sweden, Germany, Italy and the Netherlands. The projects involved are a salt desalination plant, an industrial heat plant, two central solar heating plants, solar energy and heat pump system for collective house heating and a bulb drying process. Five of the six systems have actually been build, while the project from Spain didn't make it through the feasibility stage. Due to timing problems, which can easily occur in the design, realisation and monitoring of large systems the projects from Switzerland and Italy are not included in this report.

The LSG was organised through the national projects. During the meetings progress and problems were discussed. This mechanism took care of accessibility of available international knowledge and experiences. On the other hand it appeared hard to establish a common research programme.

During the Task it became more and more evident that the general experience in the set-up, design, construction, realisation, monitoring and evaluation was the common base which can contribute to advance the international know-how. Therefor the main products of this group are the general observations and experiences (part 2 of this report).

In part 1 of this report the three systems are globally described. Part 2, as already written gives the general part of the projects. In part 3, the Appendices, the three systems and their results are described into more details.

The LSG acknowledges the IEA/SHAC-program for creating the international platform in which the valuable expertise could be used and the national funding agencies who stimulated the actual realisation of these important projects.

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PART 1: BRIEF DESCRIPTION AND ANALYSIS OF PROJECTS

2. FALKENBERG CENTRAL SOLAR HEATING PLANT (SWEDEN)

2.1 GENERAL SYSTEM DESCRIPTION

An experimental Central Solar Heating Plant with Diurnal Storage (CSHPDS) is connected to the heating plant in the district heating system of the small town, Falkenberg, on the Swedish west coast (N57°, E12°). The solar heating plant comprises a ground-mounted flat plate solar collector array and an insulated steel tank connected by a pipe buried in the ground. The heating plant also includes two wood chip boilers and two natural gas boilers.

The main objective of this project was to demonstrate a substantial cost reduction without sacrificing in performance compared to previously built plants of the same type. In Appendix A of this report the result of this system are presented in more details.
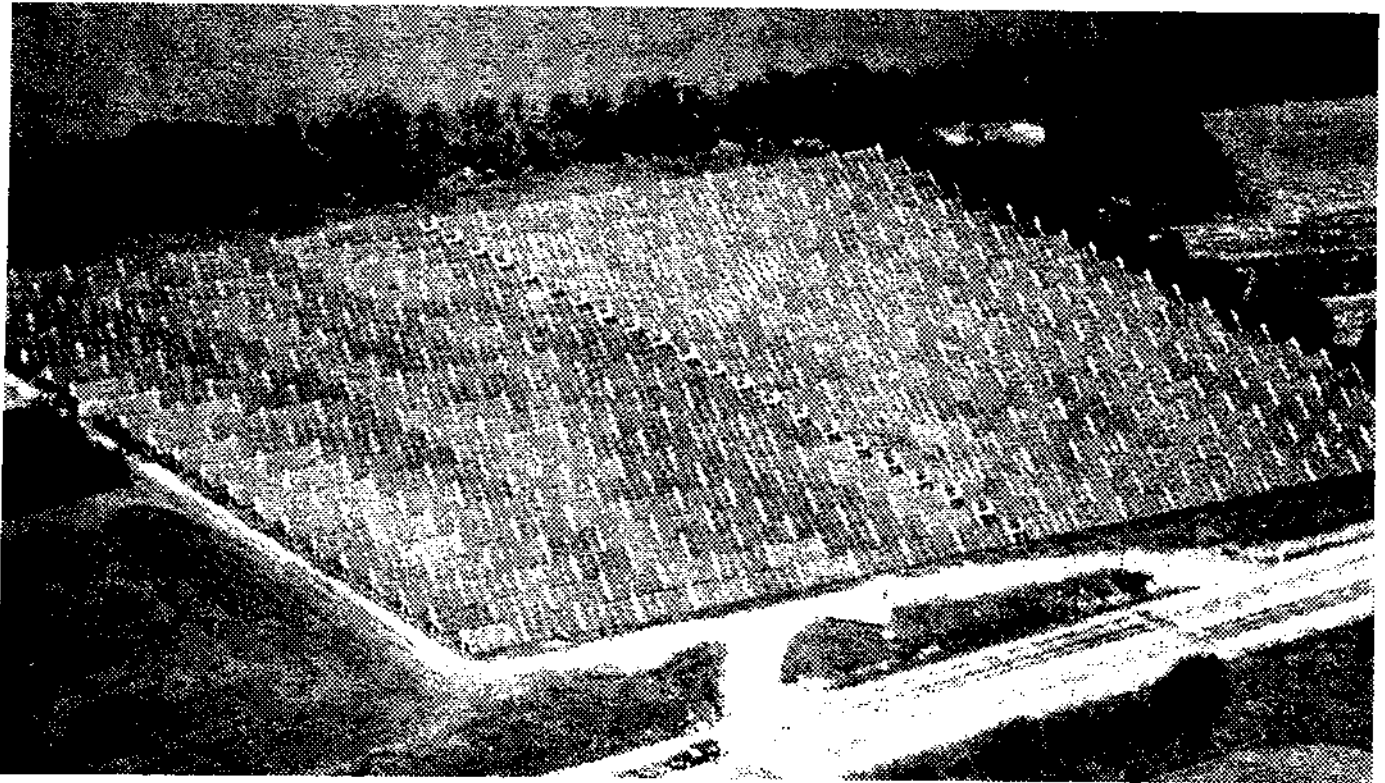

Figure 2.1   The solar collector array at Falkenberg. It is large enough to carry the total DH load during sunny periods in the summer.

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2.1.1 The Solar Heating Plant

The central solar heating plant at Falkenberg supplies heat to the district heating (DH) network and thereby replaces burning of fuels in the DH plant. The solar heating plant is designed to carry the total DH load during sunny periods in the middle of the summer. However, the solar fraction on a yearly basis will be modest. The solar heating plant acts as a pre-heating system. Furthermore, it is possible to use the tank as a buffer storage for the wood-chip boilers.

2.1.1.1   *The solar collector loop*

The solar collector loop consists of a 5500 m^2 collector array, an 720 m district heating pipe, a circulation pump, and a flat plate heat exchanger. The working fluid used is a 50 per cent mixture of water and propylene glycol. Figure 2.1 shows the collector array placed on a non-fenced field between farmland and a major road. The collectors are facing 5° East of South and they are tilted 38° from horizontal to boost the summer performance.
The collector modules are mounted on simple aluminium frames, which in turn are mounted on concrete slabs place directly on the ground. The preparation of the ground surface is minimal and thus the array looks a bit untidy.
The lay-out of the array as shown in Figure 2.2 is governed by 1) the hydraulic characteristics of the absorber strip, 2) the specific flow-rate used, 3) the shape of the property, 4) the total collector area, and 5) a requirement to limit the amount of the pipes in the array. The maximum length of absorber strips in series (approx. 100 m, i.e. 16 collector modules) is given by the acceptable pressure drop. One block of twenty-eight rows times sixteen collector modules do not fit on the property. Thus, the collectors are arranged in two parallel blocks each of which comprise twenty-two parallel rows. These in turn comprise ten 12.5 m^2 collector modules, which are connected in series with flexible hoses. At the inlet of each row there is a balancing, and a pressure relief valve. At the outlet there is a shut-off valve making it possible to isolate a row during replacement of a collector module. The collector flow is equivalent to 0.0046 kg/m^2.s of water.

The collector module (TeknoTerm AB, model HT) comprises one pane of low iron glass, one layer of Teflon film, and the selective SunStrip absorber. The absorber is approximately six by two meters and comprises absorber strips in parallel between two headers. This configuration limits the total flow resistance of the collector module. Moreover, the strips make up the dominating part of that resistance, securing a uniform flow distribution within the module. Thus, these modules are appropriate connect in series.
TeknoTerm has successively developed their technique to mount the Teflon film convection barriers. Two 6 by 1.2 meter films (50 micron) are fixed in extruded aluminium profiles, which in turn are mounted to the headers. The films are further supported by the glass-support. Thus, the films are not supported along their longer edges. The films are pre-stressed so that they supposedly do not sag when heated.

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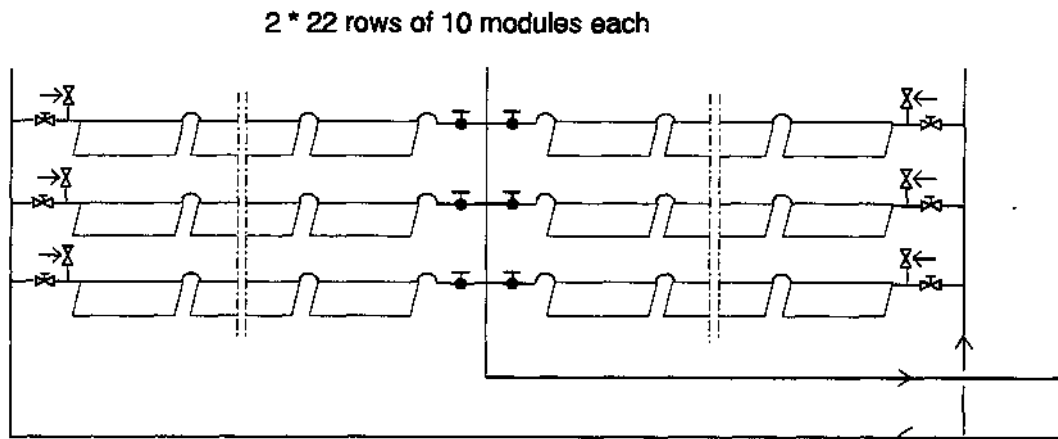
2 * 22 rows of 10 modules each

Figure 2.2.   The layout of the solar collector array. This arrangement is in essence
an adaptation to the hydraulic characteristics of the absorber strip used.

2.1.1.2   The storage

The storage consists of an above-ground steel tank, which is insulated with 600 mm
of mineral wool. The tank is 26 m tall and contains 1100 m^3 of water. The tank is
unpressurised, i.e. above the water surface there is atmospheric pressure. However,
to avoid an inflow of oxygen and as a result corrosion, an additional pressure of a few
hundred Pa is maintained by means of a water-lock and a steam boiler.
The tank and its inlets are designed to support temperature stratification. The
configuration is shown in Figure 2.3. The inlets are connected to short vertical tubes
inside the tank, the purpose of which are to suppress mixing of water of different
temperatures. The DH return temperature varies over the day, which justifies such a
device also at the inlet at the DH side.

2.1.1.3   Operating controls

The control system of the solar heating plant is simple and still it may be operated in
a number of different modes. The storage splits the plant in two sides, the modes of
which are coupled only by the temperatures in the tank. In the morning, before there
is enough insolation to collect solar heat, the circulation in the collector loop starts and
to make the temperature of the working fluid uniform. When the return temperature of
the collector loop exceeds the temperature at the bottom of the tank by a small
difference, pre-set to 4°C, the circulation in the charging loop starts.
The solar heating plant serves as a pre-heat system to the conventional DH plant. The
solar part does neither affect the control of the DH flow nor of the DH supply
temperature. However, when the temperature at the top of the tank is higher than the
required supply temperature the water from the top of tank is directly supplied to the
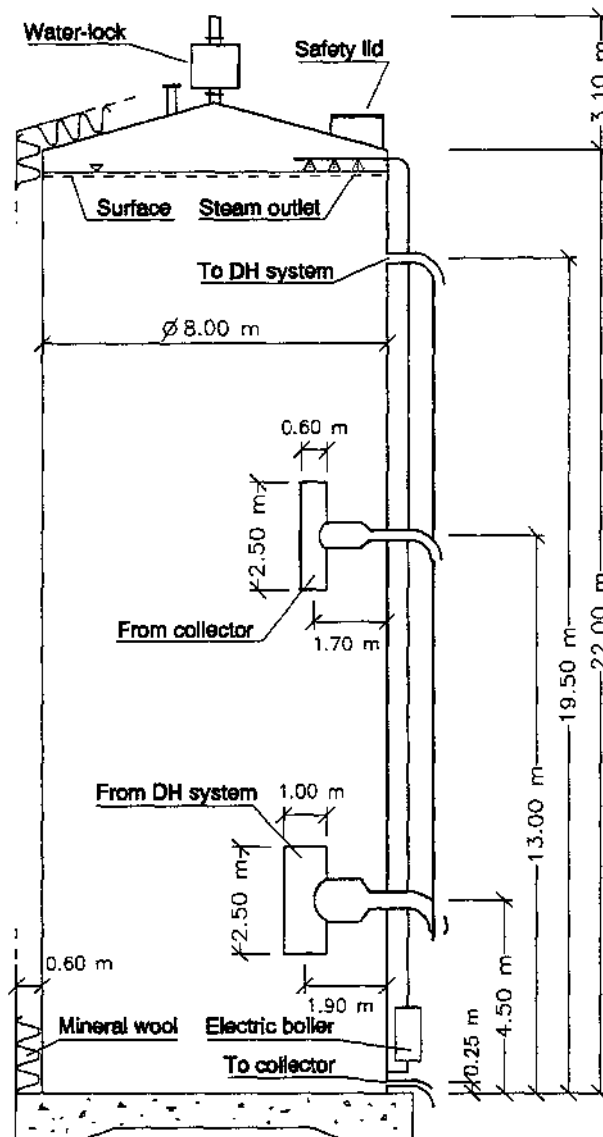DH network.

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Figure 2.3. The 1100 m³ heat storage.

2.1.2   The District Heating System

In the central part of Falkenberg, district heating (DH) services commercial buildings and 1200 households in apartment buildings. The maximum DH output is 13 MW and the annual energy delivered is 100 TJ.

The DH system built in 1985 now replaces the former boilers in 53 block heating systems, most of which were designed to work at high temperature levels. These systems are owned by the consumers and when connected to the new DH system no measures were taken to decrease the operating temperatures. Thus, the resulting DH system includes a modern primary network and several secondary networks of various standards.

The average return temperature of the DH network was fairly high, around 65°C during the summer season of 1987. To improve the performance of the solar heating plant a major effort to lower the DH return temperature was undertaken. The measures taken include flow adjustments, redesign and modification of many consumer substations.

2.2   ENERGY LOAD AND SOLAR CONTRIBUTION

During the three year period 1990--92 the solar heating plant delivered a yearly net average of 5.22 TJ (1.45 GWh) to the DH network. During this period the yearly DH load was 95.8 TJ (±3%, 26.6 GWh) and thus the solar fraction of the load, 5.4%. The yearly average of solar incident upon the collector array was 23.7 TJ (6.58 GWh) and consequently the yearly CSHPDS system efficiency was 22.0%. This result is good although it does not fulfil the design goals.

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2.2.1   Energy load

The solar heating plant serves as a pre-heating system to the conventional DH plant and the solar fraction is low. Moreover, the storage tank is relatively large and solar heated water hardly ever reaches the bottom of the tank. Thus, the solar heating plant experiences a large yearly load and the supply temperature of the collector loop is governed by the DH return temperature.

2.2.2   Solar contribution

During the three years 1990--92 the average measured yearly collector output was 6.11 TJ and the solar heating plant delivered a yearly average of 5.51 TJ ($\pm$2%, 1.53 GWh) to the DH network. Subtracting the electrical energy used to operate the CSHPDS results in the net solar energy delivered to the DH network of 5.22 TJ (1.45 GWh). Table 2.1 presents a set of thermal performance factors of the Falkenberg solar heating plant for the years 1990 through 1992. All the energy quantities refer to unit area of collector. Missing data for 30 days have been substituted by the averages for the month in question.

2.2.3   Solar collector and system efficiency

The average collector loop and system efficiency during the three years 1990-92 were:

$$\frac{Solar\ energy\ collected}{total\ solar\ incident\ in\ the\ plane\ of\ the\ collector} \approx 0.26$$

and

$$\frac{net\ solar\ energy\ delivered\ to\ the\ DH\ network}{Total\ solar\ incident\ in\ the\ plane\ of\ the\ collector} \approx 0.22$$

Table 2.1 displays these efficiencies for each separate year.

2.3   ANALYSIS OF THE SOLAR HEATING PROJECT

The project engaged many parties, each having slightly different objectives. In the planning phase the R&D aspects were emphasised. Once the decision was made to run the project the commercial interests gradually took precedence.
TeknoTerm AB designed, built, and delivered the solar heating plant as a turn-key project on ordinary commercial conditions.

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Thermal performance factor	1990	1991	1992	Unit
Total solar incident in the collector plane	4.43	4.18	4.32	GJ/m²
Total solar incident while collecting	2.87	2.66	2.93	GJ/m²
Solar energy collected	1.07	1.07	1.19	GJ/m²
Solar collector loop efficiency	24	26	28	%
Solar collector loop on efficiency	37	40	41	%
Net solar energy delivered to the DH network	0.88	0.94	1.03	GJ/m²
Solar heating system efficiency	20	22	24	%
Total energy delivered	15.9	18.0	18.3	GJ/m²
Solar fraction of total energy delivered	5.6	5.2	5.7	%

Table 2.1   Thermal performance factors of the CSHPDS at Falkenberg for the three year period 1990-1992.

For two reasons the price of the plant had to be competitive. Firstly, a prerequisite to the project was financing by a subsidised loan special to full-scale experiments in the field of energy conservation. To be qualified the project had to manifest special qualities such as advancements compared to previous plants. Price is an important key factor. Secondly, TeknoTerm AB has competitors. Thus, TeknoTerm AB needs to keep the cost low and at the same time minimise the risks of technical malfunctions. Likewise, safe operation is a prime concern to the buyer Falkenberg Energi AB.

2.3.1 Design phase

Prior to the Falkenberg project TeknoTerm AB has designed and built a few similar plants. The design was based on measured monthly data of load and temperatures of the DH network. No special problems are reported. However, in retrospect it is obvious that enough attention was paid neither to the function of the non-proven "stratification-enhancement-device", nor to the system to prevent oxygen from entering the tank. Furthermore, in retrospect the early predictions of the yearly collector yield were overly optimistic. The reason was partly the collector test method used, which overrate the collector performance.

2.3.2 Realisation phase

In the course of the Swedish solar heating programme TeknoTerm AB has developed techniques to install this type of plants. No special problems were reported from the installation at Falkenberg.

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2.3.3 Operation phase

The solar heating plant was put into operation in the autumn of 1989. Since then, it is in operation without any major problems. However, a number of problems have been encountered:

- Leakage in the connections between the flexible hoses and the collector modules has occurred. Similar collector arrays equipped with the same type of joints do not exhibit this problem.
- The Teflon film has broken and been repaired in some (approx. 2%) of the collector modules. In another maybe ten per cent of the modules the upper edge of the film is sagging permanently. Furthermore, from time to time the Teflon film adheres to the outer cover in a significant portion of the collectors.
- At a couple of occasions we observed very low flow rates and boiling in a few collector rows. Subsequently the flow distribution has been adjusted.
- Finally, the water-lock and the steam boiler do not effectively prevent ambient air from entering into the top of the tank. Corrosion in the storage tank is a growing concern.

2.3.4. The cost of the solar energy

Table 2.2 presents the price of the Falkenberg CSHPDS according to the tender of TeknoTerm, which was valid through February 1989. The CSHPDS was financed by a special loan to Falkenberg Energi AB from the National Council for Building Research.

The price of the CSHPDS 1.60 MUSD (1 USD = 7.0 SEK) does neither include costs of overhead at Falkenberg Energi AB, nor the value added tax. Dividing this price by the solar energy delivered to the DH network 5.22 TJ yields 31 USD/(GJ/a), which is the CSHPDS investment cost per yearly GJ. This is a simple figure of merit that does not depend on assumptions regarding economic factors. The yearly cost to operate the CSHPDS amounts to 0.6 per cent of the investment cost and it adds 2 USD/GJ. Accounting for the operation conditions the thermal performance of the Falkenberg CSHPDS is approximately twenty per cent lower than that of the Nykvam I CSHPDS. Prior to the Falkenberg plant the Nykvarn plant was the most cost effective among solar district heating plants in Sweden. However, the lower performance is more than compensated for by the lower investment cost at Falkenberg. Thus, at Falkenberg the investment cost per yearly G J of the collector loop is twenty per cent lower than that of Nykvam I. The same reduction in capital cost applies for the entire CSHPDS.

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Item	US$ (thousand)	US$/m2
CSHPDS		
Solar collector array	1093	199
Pipe between array and the DH plant	243	44
Storage	264	49
Revamp and adjustment of consumer's substations	141	
Design, etc.	43	
Total price according to the tender	1785	292

Table 2.2. Actual price for the Falkenberg CSHPDS, excluding value added tax. (Price level of February 1989. 1 US$ = 7.0 SEK)

2.4 DISCUSSION AND CONCLUSIONS

The main goal of the Falkenberg project is accomplished. The CSHPDS exhibits a decrease in the cost of the solar energy compared to the best plants previously built in Sweden. The cost reduction is twenty per cent.

2.4.1 Prediction of the collector performance

The long term thermal performance of the CSHPDS at Falkenberg is considerably lower than originally predicted by TeknoTerm. Misleading results from the module test is one reason to that. One used the Swedish standard (SS 1782, which is similar to the German standard DIN 4757) according to which the U-value is determined in the dark. This test method yields too low U-values leading to overly optimistic performance predictions.

2.4.2 The Teflon film convection barrier

The Teflon film convection barrier was the topic of an ongoing discussion throughout the project. Three of our observations are worth to mention.
* The Teflon film convection barrier exhibits malfunctions in many collector modules. Intermittently, it sags or it sticks to the outer cover. Moreover, the Teflon film has broken in a few modules.
* Visual inspection indicates that the convection barriers are in a better condition today after five years than they were a half a year after the installation. Shrinking might contribute to that.
* Convection barriers that initially look good may break after a couple of years. Thus, one cannot judge a mounting technique after a few months of operation.
The mounting technique of the Teflon film convection barrier needs further refinement.

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2.4.3 The storage

Corrosion inside the storage tank is the most serious problem of the CSHPDS at Falkenberg. The arrangement to prevent entrainment of air into the tank does not work. A project to address these problems is underway. Corrosion inside the storage tank is the most serious problem of the CSHPDS at Falkenberg. The arrangement to prevent entrainment of air into the tank does not work. A project to address these problems is underway. To avoid crevice corrosion the tank must be perfectly airtight. Maintaining a small positive gauge pressure will indeed prevent entrainment of air. However, steam will enter the leaks, condensate, get in contact with outside air, and form an environment for crevice corrosion. Most likely, this is what happened at the safety lid of the storage tank.

The "stratifying enhancement device" in the tank does not work as intended. The device that consists of a wide vertical pipe (see Figure 2.3) is mounted at the inlets of the tank. Measured temperature profiles show that the device causes a local mixing that involves water below the device. The temperature in the upper part of the device is noticeable lower (5-10K) than the inlet temperature. We understand that colder water from below is injected into the rising inlet flow. Outside the device a downward flow compensates for the injected water. The result is mixing.

REFERENCES CHAPTER 4

In general see Appendix A of this report for more information.
Specific references
[2.1] H. Walletun, 1995, Förbättra kundanläggningarna i Sveriges fjärrvärmesystem, (Improve the consumer installation in the district heating network of Sweden), Energimagasinet, 1995:6, Sweden

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3. GÖTTINGEN CENTRAL SOLAR HEATING PLANT (GERMANY)

3.1   GENERAL SYSTEM DESCRIPTION

The Göttingen central solar heating plant consists of two different solar systems which are installed on the roof and on the facade of a powerplant building in the town of Göttingen, Germany:
*   a hydronic system directly coupled to the return flow of the district heating network without a storage system and
*   a solar air system for preheating of the combustion air of the gasbumers.
This chapter as well as the results presented in appendix B are reporting on the collector systems; the results of the solar air system are presented separately in another IEA Task 14-Report [3.1].
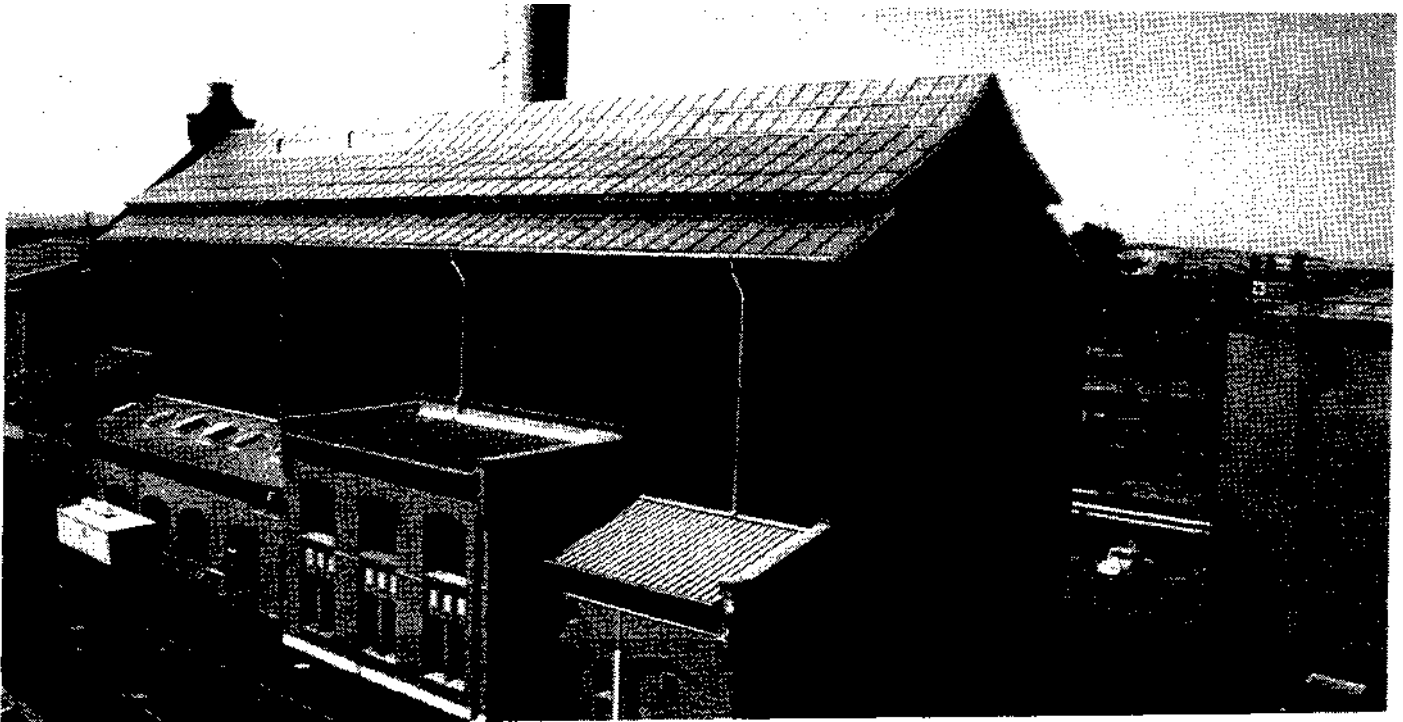

Figure 3.1. Photograph of the powerplant building in Göttingen, Germany

The photograph in figure 3.1 shows the powerplant building with the roof-integrated collectors and the "SolarWall"-system.
As presented in Figure 3.2, this type of solar system consists only of collector arrays and a heat exchanger; because the heat capacity of the district heating network acts as heat storage (up to solar contributions of 6..8 % of the annual load), no extra heat storage is needed. This shows, that this system type has the potential of substantial reduction of investment cost while operating on a high annual yield.

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3.1.1 Flat plate collector system

In September 1992 the Stadtwerke Göttingen AG started the dismantling of the roof cover and the mounting of the roof-integrated flat plate collectors.

The hydronic system consists of three collector arrays with a total aperture area of 785 m^2, installed on different roof arrays with different orientation and different slope. The largest collector field (455 m^2) is located on the south-east (E) roof with a tilt angle of 32°. The small arrays are installed on the north-west (W) and the south-east (S) roof with a tilt angle of 17° and the aperture areas are 162 m^2 for array W and 168 m^2 for array S. The collector area had been chosen according to the available and suitable roof area, because the enormous summer load of the DH network does not pose any energetic restrictions to the size of the collector array.
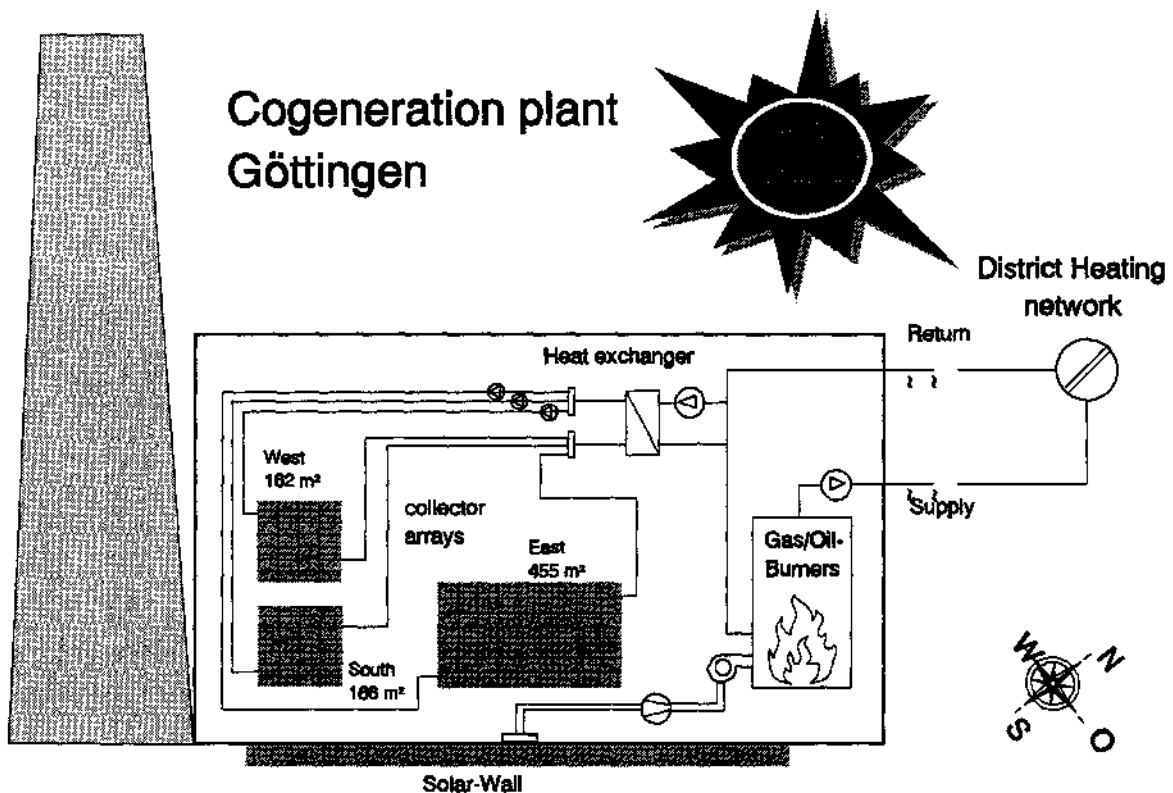

Figure 3.2. Simplified Hydronic System Schematic, showing the return flow coupling of the collector arrays

Figure 3.2 shows a simplified scheme of the integration of the three collector loops into the conventional part of the cogeneration plant.

The commissioning of the collector systems took place end of March 1993. Since then, the collector operated without problems.

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The collector arrays consist of roof-integrated, high performance flat plate collectors with selective absorber (black chrome on copper). The single glazed collector modules are equipped with a 50 m Hostaflon foil as convection barrier, fixed between absorber and glass by a special stretching and clamping technique. The distance of the foil to the cover glazing is 20 mm, the average distance between foil and absorber sheets 20 ± 5 mm. Furthermore, stainless steel wires (0.75 mm diameter) stretched by springs maintain the optimal distance between absorber and foil.

The collector consists of absorber fins connected in parallel. Most collector modules have a size of 6.0 m^2 or 7.5 m^2, also smaller modules have been installed in order to cover the whole roof area.

Collector efficiency measurements have been carried out by different institutes in Germany and in Switzerland [3.2]. The investigations at the ISFH based on the ISO-DIS 9806-1 gave the following experimental results (referred to the absorber area) [3.3]:

$$\eta_0 = 0.758 \qquad a_0 = 2.88 \ W/m^2K \qquad a_1 = 0.013 \ W/m^2K^2$$

In the collector system a water / propylene glycol (67 / 33 %-vol) mixture is used as heat transfer medium. The different orientations of the three collector arrays require three independently controlled collector loops which are connected in parallel to the heat exchanger. Furthermore, each collector array loop is equipped with a separate pump in order to reach the optimal flow rate in each collector loop.

3.1.2 Cogeneration plant and district heating network

The Stadtwerke Göttingen AG operate a district heating power station consisting of two high-pressure superheated-steam boilers with two subsequent steam turbines delivering a maximum power output of 5 MW$_{el}$. Furthermore, two high-pressure steam boilers are installed in order to cover on-peak consumption in winter and for the low-load period in summer. The whole available heat capacity in the cogeneration plant is about 65 MW$_{th}$. The installed supply network of the local utility of Göttingen has a length of 12 km and in the city area about 140 large buildings are supplied with thermal energy. Between May and September the district heating power station only produces thermal energy meanwhile the cogeneration mode is restricted to the heating period.

3.1.3 Solar system integration

The simplified scheme in figure 3.2 shows the integration of the three collector arrays into the cogeneration plant. The three parallel collector loops are connected via a heat exchanger to the return flow of the DH network in order to preheat the fluid in the return flow of the DH network. The nominal rating of the gasketed-plate heat exchanger is about 600 kW based on a volume flow rate of $V = 40$ m^3/h and a temperature difference of $\Delta T = 12$ °C.

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3.2 ENERGY LOAD AND SOLAR CONTRIBUTION

3.2.1 Energy load

The annual heat demand in the main DH network is approximately 360.000 GJ (100.000 MWh) in which the summer load between May and September is less than 15 % of the total annual load. The return temperatures in the network differ during the year between 65 °C and 75 °C depending on the ambient temperature and the combined heat and power mode.

3.2.2 Solar contribution

The detailed analysis of the solar contribution played a major role within an extensive scientific research programme, funded by the German Federal Ministry of Research and Technology. These investigations have been conducted both during the pre-design and design phase as well as during a 2.5 years monitoring period.

In order to analyze the energetic behaviour of the solar system a data acquisition system has been installed in the cogeneration plant in Göttingen which operates continuously, scanning 65 sensors in 10 s intervals and storing 5 or 10 minute average values since the begin of April 1993.

Based on this monitoring program, several investigations have been made concerning the following items:

- collector efficiency based on hourly data,
- daily Input/Output - diagram,
- annual and monthly results,
- comparison of measured collector array yield to simulation results of the design phase.

Results of these investigations are presented in the appendix in chapter B-5 and B-6. A summary of the measured solar system performance is given in chapter 3.3.2.5.

3.2.3 Collector efficiency

In order to analyze, if the collector modules are performing as expected, a comparative investigation of in-situ collector array efficiency and stationary indoor test results has been carried out. This method of analysis is independent of the operating temperature, which depends on other operating conditions of the conventional part of the system. Figures 3.3 and 3.4 show the results of an indoor test as well as the hourly efficiency values of the east collector array in August during 1993, 94 and 95. The comparison provides a good correspondence to the stationary test results. For dt/I-values of about 0.075 $K*m^2/W$ efficiencies of about 50 % have been achieved - which corresponds to collector operation temperatures of 50 K above the ambient temperature with irradiation values of 650 W/m^2. For these conditions the test results are nearly the same.

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A comparison between earlier (Aug. 93) and later (Aug. 94/95) values indicate a small difference which are caused by atmospheric deposits on the collector cover. Further investigations are shown in the appendix in chapter B.4.1.4.
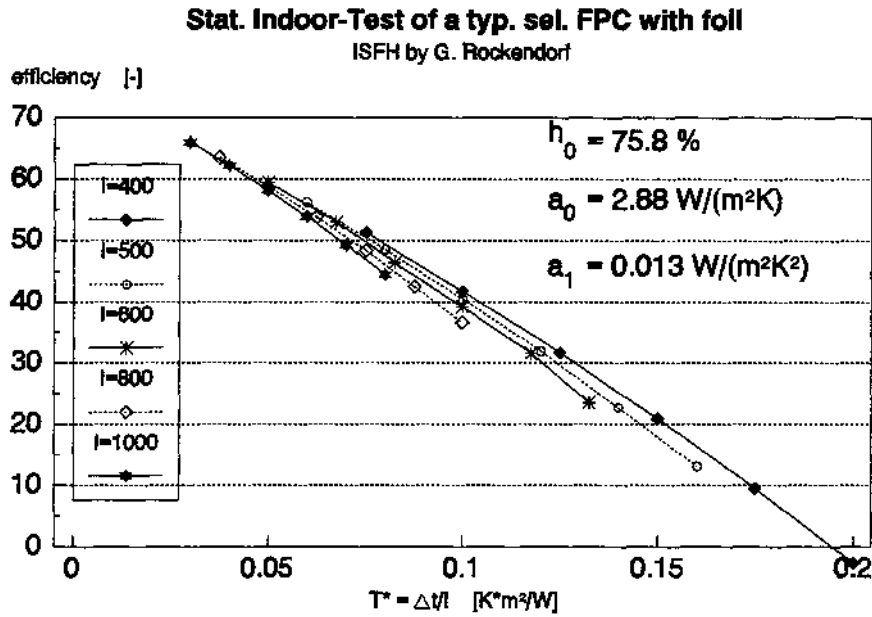
Stat. Indoor-Test of a typ. sel. FPC with foil
ISFH by G. Rockendorf

efficiency [-]

$h_0 = 75.8\%$

$a_0 = 2.88\ W/(m^2K)$

$a_1 = 0.013\ W/(m^2K^2)$

I=400
I=500
I=600
I=800
I=800
I=1000

$T^* = \Delta t/I \quad [K^*m^2/W]$

Figure 3.3. Stationary indoor collector test of the SOLVIS selective flat plate
collector.

East collector array
hourly data August 1993/94/95

efficiency [%]

Aug. 93   Aug. 94   Aug. 95
 *   .   o

$T^* = \Delta t/I \quad [K^*m^2/W]$
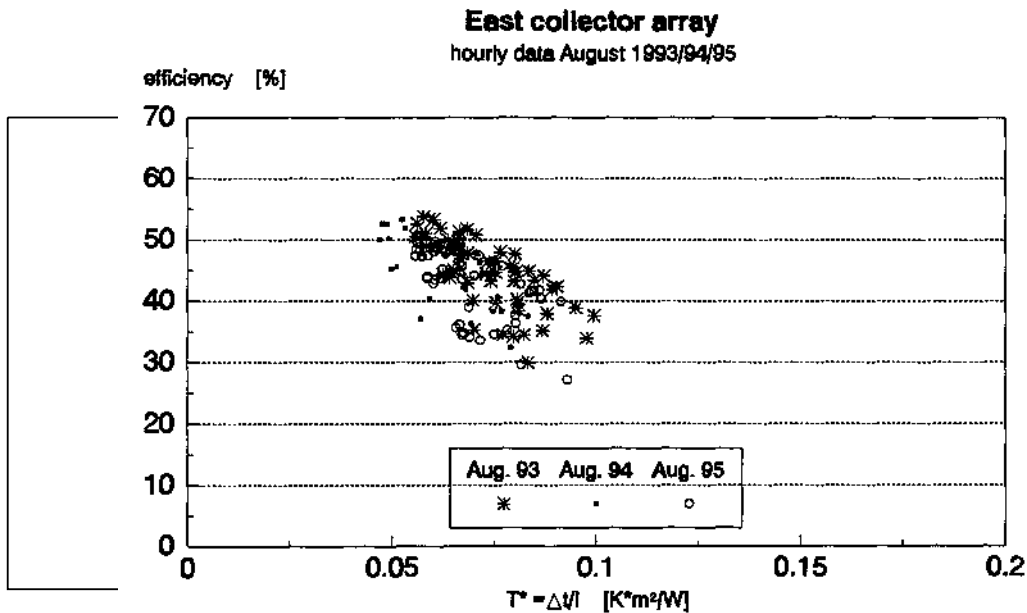
Figure 3.4. Measured hourly efficiency data east collector array (with capacity
correction (see Appendix B.6.1)

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3.2.4 Input/Output-verification

The Input/Output-correlation builds an easy method for the evaluation of the daily collector yield. The diagram compares the measured collector array output of the east array in April 1994 with the regression line based on measured data of August 1993. This comparison demonstrates two aspects: first, an Input Output regression, that can be used to check the operation in other months, can be obtained with one month of experimental data, second, the diagram shows, that there is no degradation in the mean time.

Input/Output-Diagram
East collector array April 1994

Daily collector output [kWh/(m²·d)]

Measured data
■

Regression line, Aug.'93
───

Daily Irradiation [kWh/(m²·d)]
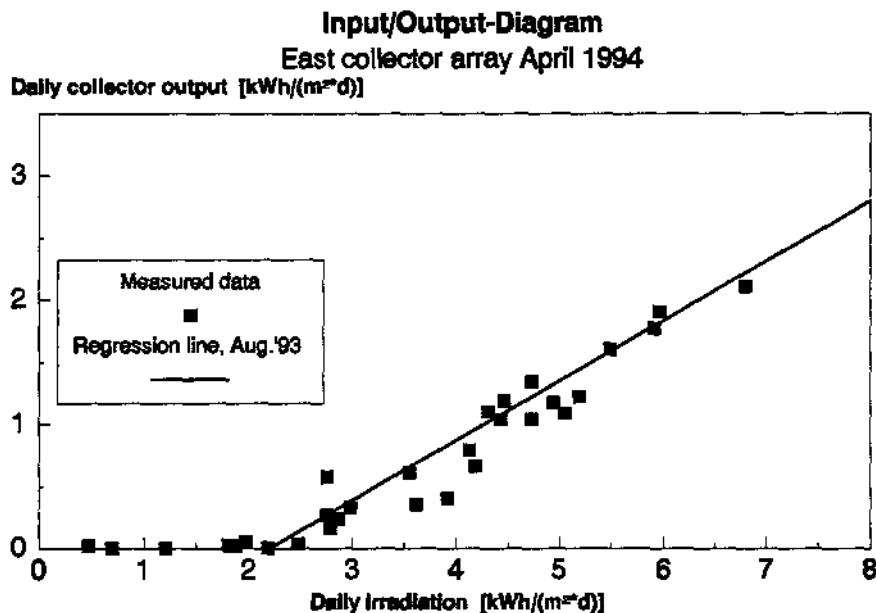
Figure 3.5. Input/Output Regression line based on August 93 data compared to April 94 data

Apart from this, the Input/Output-method has been used to point out either if the collectors are in good operating conditions or if there is a failure in the monitoring system. In order to perform an automatic supervision of the collector arrays operation, in autumn 1994 the Input/Output-correlation has been integrated into the data acquisition system in Göttingen. As an example, Figure 3.6 shows an illustration of the computer display for the analysis of 10 days operation for the three collector array. Experiences up to now indicate that the Input/Output-correlation facilitate both the permanent, low-cost in-situ operation check of the solar loop as well as an easy and fast check of the system performance.
Regression values of the collector array yield over a 10 days analysis period
A detailed analysis on the validation of the input/output regression method against measured data as well as possible applications of the method in view of a permanent in-situ commissioning tool are described in a separate report of IEA Task 14 Subtask on Dynamic Collector- and System Testing.

Routine for the indication of ' Input / Output - Controller ' - Data Summary

Available data basis: 60 days
Analysis sequence cover the last 10 days

Array	Start	Stop	Collector output measured [kWh/m²d]	I/O-regression [kWh/m²d]	Deviation [%]	anal. days
Array 1	21.06.	30.06.	1.396	1.363	2.36	10
Array 2	21.06.	30.06	1.508	1.443	4.31	10
Array 3	21.06.	30.06.	1.605	1.551	3.36	10

Change of analysis length? . . . . Code number !
forward ? . . . . one button ! / back ? . . . . ESC !
Display of all days (Array 1 . . 3) . . . . 1, 2 oder 3 !

Figure 3.6. Computer Display comparing the measurement and Input/Output. The deviation between measurement and Input/Output-Regression values of the 10-day average collector array yield is smaller than 5 % of average daily yield. In total it's possible to check the last 60 days of every collector array on the display in order to compare the measured and the I/O-predicted system output.

3.3 ANALYSIS OF THE PROJECT

3.3.1 Pre-design phase and design phase

Pre-design phase
First pre-studies of the Göttingen project were made in view of connecting the collector array to a modern, relatively small branch of the DH network that operates with lower temperatures of about 50 °C in the return flow.

Design phase
At the beginning of the design phase of the project it was recognized, that the return flow in this small network would not be big enough to take up the solar energy in summer: available solar heat under good summer operating conditions would have exceeded the too small daily load, which would have resulted in very high operating temperatures because of insufficient storage capacity in this small loop.
In order to demonstrate this relationship, several simulations were carried out to calculate the solar system output as a function of the DH network return temperature. According to these simulations, the average collector output reaches values as mentioned in the following Table 3.1.

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Return temperature	70 °C	60 °C	50 °C	40 °C
Average collector output [kWh/m²a]	177	263	311	365
Average collector output [MJ/m²a]	49	73	86,4	101

Table 3.1: Results of the simulation with ISFH and TRNSYS programs

Requirements

Based on these results it was decided to connect the solar system to the main DH network together with a commitment of Stadtwerke Göttingen to lower the network return temperature to approximately 40 °C.

Solar energy cost

The simplified system concept and the cost reduction of large collector modules lead to specific system costs of 396 US\$/m^2 (640 DM/m^2). Together with the high specific system output based on a return temperature of $t_{RL} = 40$ °C -, a solar energy price of about 36.1 US\$/GJ (0.21 DM/kWh) has been calculated, based on a lifetime of 20 years, an annual interest rate of 8 % and a share of 1.5 % for operational and maintenance costs. This solar energy cost has been calculated by dividing the annual capital plus maintenance cost by the annual collector array yield without considering any funding in the capital cost.

3.3.2 Realization

3.3.2.1   Collector arrays

The mounting of the collector modules took place between September and November 1992 by the Solvis Company from Braunschweig, Germany. For the installation of the big collector modules it was necessary to use a big crane to carry the modules on the roofs. On the small arrays it was possible to carry about 8 collectors in a package on the roofs.

The installation of the pipings, the control units and the heat exchanger was finished in the beginning of March. After that the collector loops were filled with the water/glycol-mixture and commissioned. Since the end of March 1993 the system operates automatically and without any major problems.

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3.3.2.2   Operation and maintenance

In the first period of operation it took some weeks until some condensate, that had penetrated into the collector modules during the very rainy installation time of fall and winter '92, disappeared by natural drying through some air vents. Afterwards this problem did not occur any more.

According to visual inspection, the collectors are in a very good shape despite some broken steel wires inside the modules, which however do not harm the correct function of the convection barrier. The most noticeable thing is the large extent of soiling on the cover glasses in comparison to other collector systems that are placed in the countryside.

Till autumn 1995 only one leakage occurred in a safety valve caused by a failure of a control unit in the east collector array which caused temperatures to raise above 100 °C in the collector loop. Furthermore two glass covers in a collector module have been exchanged against new ones in order to measure changes in transmissivity; results of the corresponding investigations are stated in the appendix in chapter B.4.1.4.

The Hostaflon foil which is used as a convection barrier in the modules caused no problems even in the collectors where the steel wires are broken. By visual inspection no degradation, deformation or lengthening can be observed, leading to the conclusion that the way this collector manufacturer fixed the foil into the collector module seems to be a very good solution.

Some problems occur in the roof integration concerning the rain tightness of the collector arrays. In the small collector fields it is solved but in the large east collector array it is not yet clear how to tighten some minor parts of the collector roof.

Up to now no real maintenance work had to be done by the utility company. In future an Input/Output-controller unit will be installed in the control-room in order to recognize eventual operational failures.

3.3.2.3   Control strategy

The different orientations of the three collector arrays required three independently controlled collector array units which operate in dependency of the absorber and the DH return temperature. In order to optimize the control strategy different operating modes have been tested by changing the temperature differences for the switching conditions.

As a conclusion of these experiments it has to be mentioned that most problems concerning system control are linked to the very high return temperatures in the DH network.

3.3.2.4   DH network return temperature

The major problem in the Göttingen solar district heating project is caused by the high DH return temperature. Although in the first period of the project, changes in the operating mode of the cogeneration plant led to a substantial reduction starting from 90 °C at project start to 70 °C now, but for different reasons it was not possible to reach lower values until today.

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Some attempts were made by the installation of different controllers at several substations acting on return temperature and flow rate as a function of actual load and supply temperature but this measure was not very successful.

3.3.2.5   *Measured Performance*

As an example for the annual performance of the three collector arrays, Table 3.2 presents the irradiation, collector output, measured and simulated efficiencies for the first monitoring period from April 1993 to March 1994.

Array	Irradiation GJ	(MWh)	Collector output GJ	(MWh)	measured efficiency[%] $t_{RL} \sim 72\ °C$	design phase efficiency [%] $t_{RL} = 40\ °C$
West	31.4	(113)	3.9	(14)	13	33.5
South	37.2	(134)	6.1	(22)	17	39
East	103	(371)	20.6	(74)	20	39
Sum	172	(619)	30.8	(111)	18	38.2

Table 3.2: Annual results of the first measuring period April 93 to March 94

As already stated, the return temperatures are still high in the vicinity of 70 °C due to unforeseen problems in modernizing the client substations. This has to be considered if the solar performance for measured (72 °C) and predicted (40 °C) return temperatures are compared. As shown in Table 3.1, simulated collector yield based on measured collector efficiency parameters for 70 °C is very close to measured performance, indicating that no collector degradation occurred.

3.3.3 Analysis of results

Solar system
Two major results were obtained by the detailed analysis of the measured solar energy delivered by the collector arrays:
*   the collector arrays are operating according to their predicted efficiency curve. This has been verified by comparing the in-situ measured efficiency curve with that of standard collector efficiency tests. This documents, that there is no degradation of the collector itself over the measured period from March 1993 to August 95.
*   however, the collector array output is substantially lower than calculated during the design period, because the actual operating temperature of the DH load of 70 °C is still much higher than the 40 °C scheduled during the design phase. Thus the temperature difference to ambient temperature - typically 20 °C in summer time - is 50 K instead of 20.. 30 K, resulting in a tremendous increase in collector losses.

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DH Network

In spring 1995 a big investigation program has been set up to estimate the possibilities for lowering the return temperatures in the DH network. This program includes measurements at several substations as well as surveys of the consumer installations. These investigations will lead to an extensive concept for the whole DH network and we are hopeful that this concept will be put into an action plan in the near future.

3.4 OBSERVATIONS AND PROJECT EXPERIENCES

Project planning
- Check match of load, (i.e. daily, weekly load profile, temperatures,) with useful solar system output (including effects of intermediate storage in the district heating network).

District heating network
- The combination between solar and conventional systems can be useful to point out misdevelopments in the existing district heating techniques.
- Check of possibilities and potential for lowering the return temperature. This should include both technical aspects of the renovation and / or revamp of the individual substations as well as legal and contractual considerations and responsibilities (ownership, supply-contract client-operator).
- Besides normal work for the evaluation of the solar system new concept for the optimization of the district heating substations should be considered.

Solar system
- Control-criteria for collector start up should be reviewed, especially with high return temperatures. The district heating return temperature might not be the optimal reference temperature. Instead, temperatures in the secondary network, cooling down to ambient temp. at night, could be pre-heated before reaching DH-operating temperature.
- Control system: temperature controlled collector systems give only reduced possibilities for the variation of control strategies (i.e. irradiation based control strategies could give more flexibility).
- Flat plate Collectors: no collector degradation (even with rather high temperatures)
- Flat plate collector: in-situ collector array efficiency is very close to stationary test data of individual collector modules.
- Flat plate collectors: lower efficiencies of about 5 % caused by soiled covers seem to be a result of higher air pollution in the centre of big cities, especially near to central railway stations where big diesel engines are used. The eventual impact of emissions related to the flue gas of the power plant could not be investigated.

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- Anti-convection barrier: spring loaded steel wire is a good solution to prevent foil contact to the cover glass and the absorber. However careful fixing of the wire is mandatory.
- Anti-convection barrier: after two and a half year in operation no visible degradation or length difference can be detected. By visual inspection, no contact between foil and absorber could be observed in any of the collectors although some steel wires are broken.
- Collector orientation: the observed performance reduction due to high operating temperatures is different for the three collector orientations. As high operating temperatures require high irradiation levels, the operating time of the West array is much shorter due to its low average irradiation levels as compared to the East and South collector arrays.
- shading: causes some difficulties to take into account in the evaluation, especially for the hourly efficiency evaluation.

Monitoring program
- Extreme operating conditions: interference voltage, high ambient temperatures, etc. For example high voltage peaks which appear during the start up of the turbine-generator cause damages of the fuses in the flow meters. Furthermore, at several occasions, the magnetic flow transmitter had some failures which might also be caused by these severe environmental conditions.
- Input / Output - correlation can be used both to point out failures in the monitoring system as well as a tool for system operation check.

REFERENCES CHAPTER 3

In general see Appendix B of this report for more information.
Specific references
[3.1] McClenahan, Pfluger, Fisch 1996
        IEA Task 14 report on solar walls, to be published

[3.2] U.Frei-92, cf. appendix-B

[3.3] G.Rockendorf-92, cf. appendix-B

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4   LISSE SOLAR BULB DRYING SYSTEM (NETHERLANDS).

4.1 SYSTEM DESCRIPTION

4.1.1   General description.

Based on a detailed analysis of the energy needs of the bulb factory in Lisse [4.1], the yearly heating load is about 5.7 TJ. A first analysis on the possibilities for a solar heating system combined with the boundary conditions of the owner of the plant showed the global dimensions of the solar system. These are a collector field about $1000 \ m^2$ and a seasonal store of about $1000 \ m^3$, enabling a significant solar contribution to the future energy demand of the plant. Next a global comparison of the price/performance ratios of several systems was made, including a system with air collectors and no storage at all. The price indications used in this comparison were based on the information that was available at that time. The fluid based systems with a storage turned out to be considerably more cost-effective than the alternatives. Between a system with $1000 \ m^3$ store (short/long term storage) and a system with a $100 \ m^3$ store (short-term storage) the economical difference turned out to be small. However, from the research and development viewpoint, the long-term storage system is much more innovative and interesting. The seasonal storage tank will be charged and discharged two times a year due to the heating load of the plant. (see fig. 4.1). Moreover, high solar coverage fraction are more interesting in the future energy balance of the factory. In Appendix C the results are presented in more details.
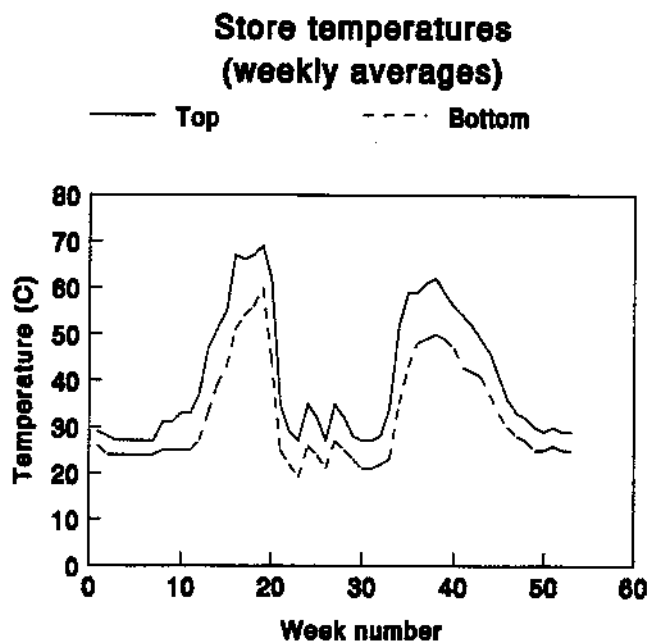
Figure 4.1. Top and Bottom temperature storage

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In the complete system several components are distinguished:

- Three parallel fields of collectors. The total area is 1139 m^2. Each branch is a series connection of two types of collectors (standard and standard with convection barrier);
- An insulated 1000 m^3 underground seasonal water storage, located near the building, with possibilities for a new building on top;
- Air preheaters (heat exchangers) which are installed in the drying wall for drying the bulbs.
- A heat exchanger to a water-filled floor heating system.

The heat, captured by the collectors, is stored in the 1000 m^3 water storage. The storage will be constructed in such a way that it can serve immediately as the floor (foundation) for a new building.
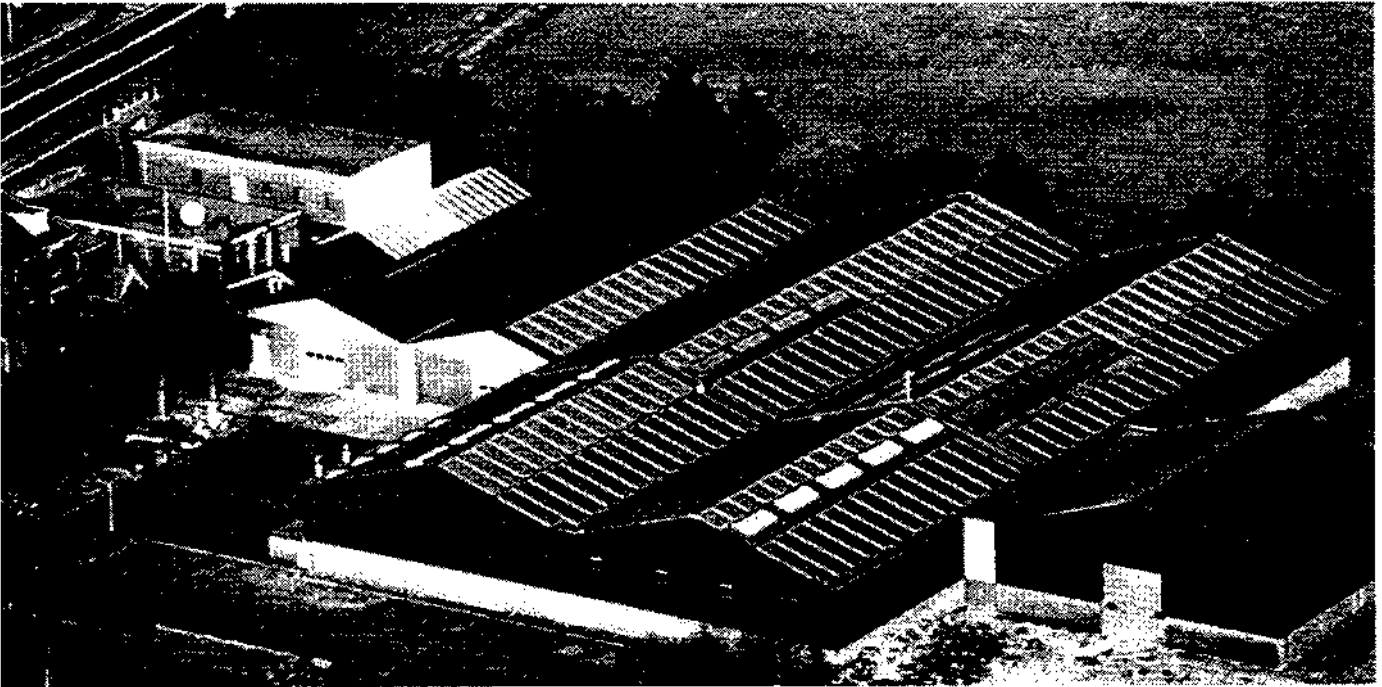
Fig 4.2   Overview picture of the bulb plant with solar system

The heat transport medium in the collector circuit is a 37 % glycol and 63 % water mixture. In the other circuits 100 % water is used. The store is separated from the rest of the system by heat exchangers. Inlet diffusors take care for the optimal stratification of the storage.

The collectors will be placed on the roof of the largest building and the building next to it. In this way the total area can be extended to 1139 m^2 without having to cover too many small roofs. The total collector area is divided in three fields, one field on each suitable part of the main roof (458 and 557 m^2) and one field on the smaller roof (134 m2).

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Five air-to-water heat exchangers will form the solar addition to the drying wall. They will be placed directly in front of the conventional heater units and heat/preheat the incoming ambient air. If the air has not reached the desired temperature after passing these heat exchangers, the conventional heating system will switch on and heat the air to the desired temperature.

The floor heating system will consists of plastic tubes which are covered by concrete. In figure 4.2 an aerial photograph of the factory including solar system is given. In figure 4.3 the scheme of the realised system is given.
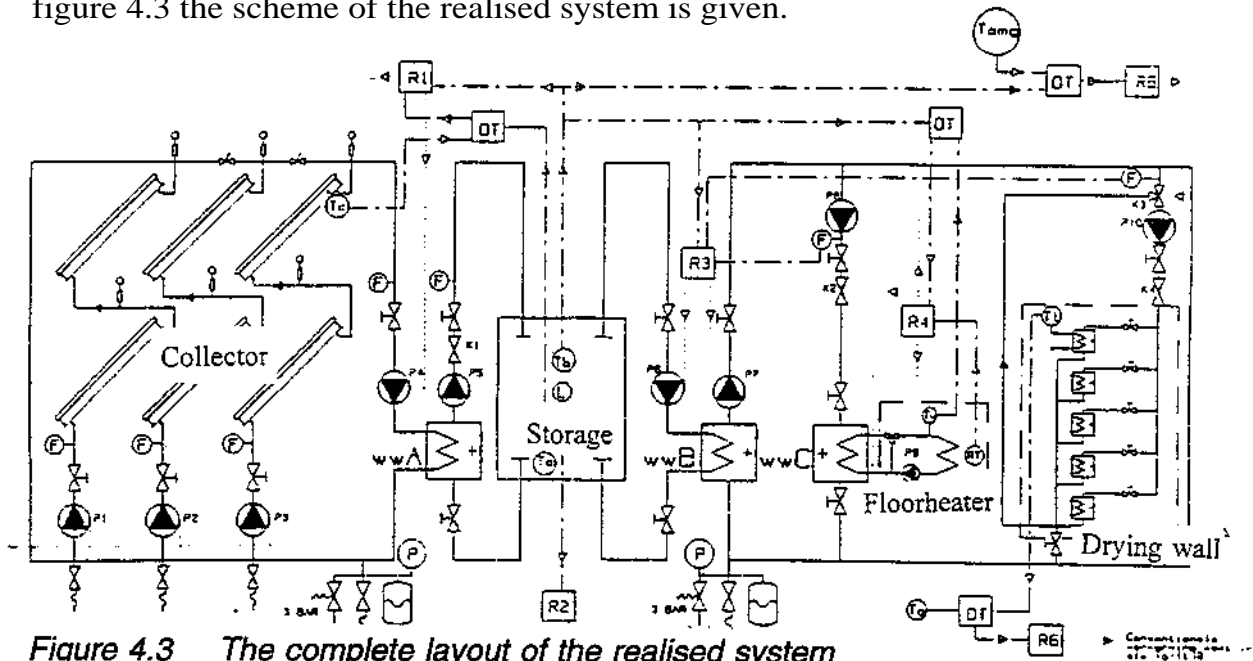
Figure 4.3   The complete layout of the realised system

For the collector circuit a normal Delta-T controller is used. The pumps switches on at a temperature difference of 15 K between the collectors and bottom of the storage. When the temperature difference drops below 1.5 K, the pumps switch off.

During normal operation, the store temperatures will stay between 20 and 75 °C and the risk of overheating is small. If at any time the temperature in the upper part of the store rises above 85 °C, a thermostat switches the collector pumps on. The collectors will then be used as coolers until the temperature in the store has dropped below 80 °C.

In case of overall failures a safety valve is mounted to secure against high pressures.

In the drying season (from half May to half August) the drying wall is in operation continuously. The five additional heaters for the solar system will have a common control unit. In normal operation, they will deliver only a part of the heat demand. The five conventional heaters are controlled individually to supply the remaining heating demand. On the occasions that there is a low heat demand, the hot water temperature to these heaters will be reduced by thermostat valve. When the store is too cold, the heaters will be switched off.

In the rest of the year only one of the five heaters is active, the other four are switched off by manual valves. This one heater will heat up recirculated air. The control will be the same as described for the drying season.

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4.1.2   Specific description of the collector array

The collector field consists of approximately 40% collectors with convection barrier and approximately 60% standard collectors.
After gathering information from the different collector suppliers, especially in Sweden, a method was developed to attach the teflon layer in the collector framework.
The main points in this method are stainless steel wires on a distance of about 0.2 m from each other, on top and below the teflon foil. At the sides of the collector, the teflon is clicked between aluminum profiles.
On top of the roof of the buildings of the factory so called U-profiles are mounted, in which movable plastic blocks were placed. On top of this plastic blocks the collectors are attached. With this method the collectors can be moved in a horizontal way, so that the connection of the header can take place afterwards in a very simple way.
In the header pipings several compensators have been used to prevent damage on the collector-connections by thermal expansion. The diameter of the header varies from 15 mm at one end of the roof to 54 mm at the other end in order to get good flow distribution through all the collectors.
The dimensions of the collector fields are adapted to the available roof length. There are three separate fields of respectively 289, 350 and 108 collector modules. In total 1139 m^2 collector area is placed. The slope of the roofs is about 20 °. The orientation is 55 ° from south into the direction south east.
The collector circuit operates only on one pump. However, in order to prevent calamities two pumps are used alternately.

4.1.3   Storage system

The heat storage as part of the solar energy system, had to be specificly designed. The special requirements of the storage, as well as the specific soil conditions and groundwater level didn't allow for a standard construction.
The storage had to meet the following requirements:
• storage capacity: approx. 1000 m^3
• temperature resistance 25°- 80° C
• the top of the storage to be used as factory-floor
• durable insulation on all sites of the store
• no water leakages in-or out the storage

Special attention for the construction was caused by the fact that the groundwater level will vary between 0.6 and 1.0 m
the storage a floating vessel during construction and/or maintenance situations, with an actual danger of rising.
Apart from this, the requirement that the top of the storage should be used as factory floor a foundation with concrete pilings through the storage tank was unavoidable.
The construction of the storage turned out to be the most critical and difficult element of the system.

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In chapter 6.3 and the appendix C the construction and encountered difficulties are described in more detail. Finally the storage tank was constructed with polystyrene on the top and the bottom. The bottom of the store is ballasted with concrete to avoid floating of the polystyrene insulation. The store walls are insulated with foamglass with a special coating on top to prevent etching.

Heatexchangers outside the store are used to load and unload the heat in the tank. In order to stimulate stratification in the storage inlet diffusors in the collector as well as the heating load circuits are used. The inlet velocity of the fluid should be very low in order not to cause mixing in the store.

In figure 4.4 the realised store is schematically presented. At this moment, as foreseen in the design, on top of the storage a building is realised.

The final design showed the parameters given in table 4.1. [4.2]

Storage content	1000 m³
Seize	20 x 20 m
Height of the storage inside	3250 mm
Wall insulation	Foamglass 150 mm
Coating on wall insulation	PC 88
Floor (base) insulation	PS 300 mm
Floor ballast	Concrete 250 mm
Top insulation	PS 100 mm

Table 4.1   The final design parameters of the storage tank.
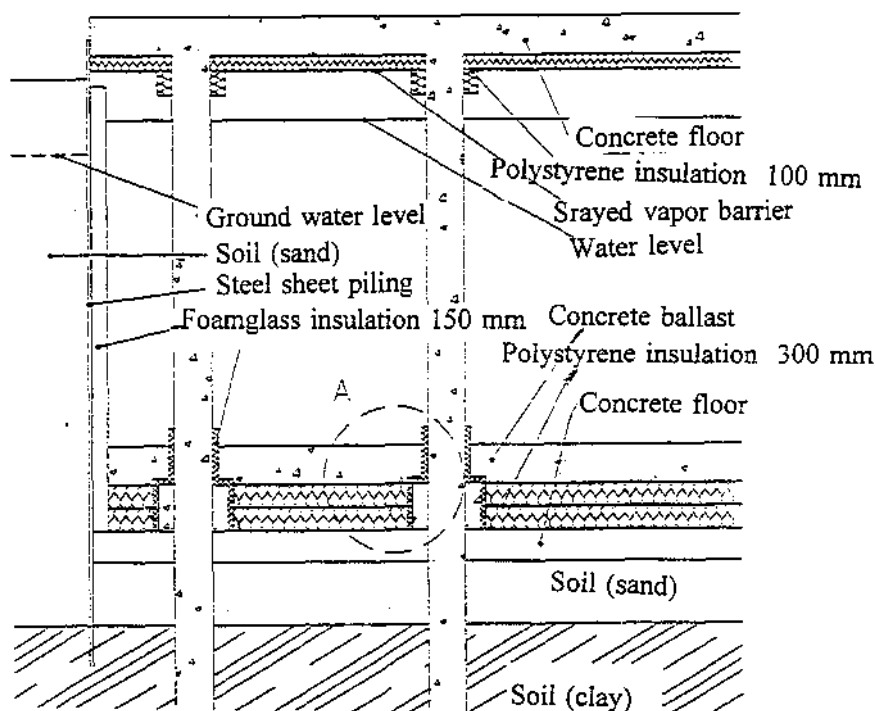
Figure 4.4 Schematic presentation of the store.

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4.1.4 The heat distribution

The main heating load is the drying wall, while the second load is the floor heating. The drying wall is a wooden wall with five sections, each section has two parallel water-to-air heat exchanger for heating the air and two fans for blowing the heated air (150000 m^3 per hour for the total installation) through the boxes with bulbs. The upper heat exchanger is connected to the solar system, the lower one is connected to a gas-fired heating circuit. In front of the wall boxes with bulbs are placed. These boxes can be placed in five rows (the five sections). Boxes can be placed on top of each other and placed in a row, enabling large quantity of bulbs to be dried. The air flow from the sections is adjusted by flow controlled fans. The five sections can be used and controlled individually.

The second heat load is the floor heating. The floor heating is used for conditioning of bulbs.

In the heating demand circuit two pumps can be distinguished. One small pump for a low heating load such as the floor heating or only one section of the drying wall. The large pump is switched in at larger heating demands. By adjusting the flow to the heating demand the stratification of the store is kept as good as possible.

4.2 ENERGY LOAD AND SOLAR CONTRIBUTION

4.2.1 Energy Load

The measurements started in december 1994 and continued during 1995 (and also in 1996). During 1995 the solar heating plant delivered 596 GJ to the heating demand of the drying processes [4.3]. In 1995 the overall heating load was 917 GJ and thus the solar fraction was 65%. The yearly solar irradiation on the collector fields was 4158 GJ and consequently the yearly system efficiency is 15%. Although the solar fraction is high, the overall performance is lower then the design values.

The much lower heating demand (3-5 times) also caused higher temperatures in the storage tank, which causes again higher heat losses.

Probably the much lower heating is partly caused by a very warm summer (record). Moreover, in the original design a growth in the turnover in the future was foreseen, causing a higher heating load then at that moment. This increase is not yet realised.

4.2.2 Solar contribution

Based on the monitoring period of about 1 year measuring results are available with respect to the solar energy contribution and the overall energy usage.

Detailed measurement are carried out on the temperatures, fluid and energy flows and climatic conditions. The measurements started in December 1994. Results of the measuredments are presented in more detail in Appendix C.

An overview of the heat flows in the solar system is given in table 4.2.

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Month	Solar	TAmb	Collect or	Drying Wall	Floor-heater	Store	Balance	Store Temp.	Auxiliary
	[GJ]	[°C]	[GJ]	[GJ]	[GJ]	[GJ]	[GJ]	[°C]	[GJ]
jan	78	4.5	12	0	7.4	7	-3	21.7	18
feb	131	7.0	34	0	4.6	1	28	22.0	0
mar	328	5.9	93	0	0.0	41	52	32.0	0
apr	435	9.0	126	32	0.0	63	32	47.2	12
may	641	12.7	235	167	0.0	10	58	49.7	138
jun	602	14.3	217	136	0.3	-10	90	47.2	69
jul	674	19.8	233	115	6.9	50	61	59.4	9
aug	614	19.6	195	74	-1.1	12	110	62.4	31
sep	288	14.6	51	11	-0.6	-18	59	58.0	32
oct	207	13.1	44	20	2.5	-49	70	46.2	6
nov	96	7.2	12	4	12.7	-47	43	34.8	4
dec	65	-1.0	2	1	5.6	-41	36	25.0	32
1995	4158	10.6	1253	558	38	21	664	42.1	321

Table 4.2   Monthly energy flows and year results as measured in 1995.
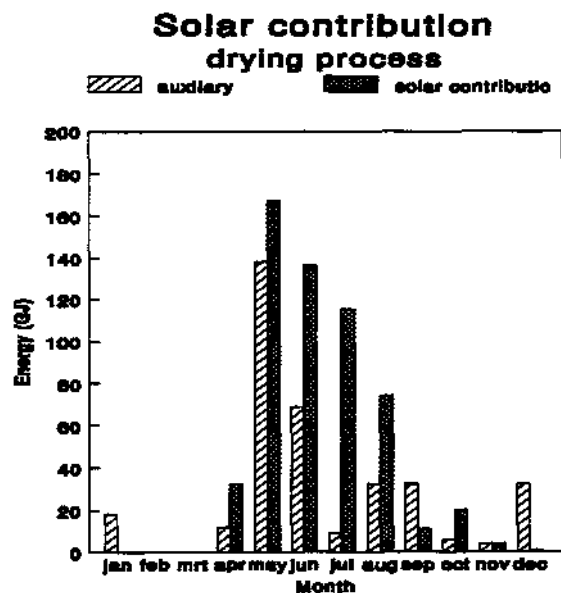
Figure 4.5 The solar contribution to the energy load of the Lisse system

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In figure 4.5 the solar contribution to the drying wall and floor heating is presented. The high solar fraction can be seen in this figure. On the other hand the overall heating load of the drying process (summer) is much lower then expected (3-5 times). The temperature of the storage tank during the monitoring period is given in figure 4.6. Due to the lower heating load the temperature in the store stays rather high in the summer period.
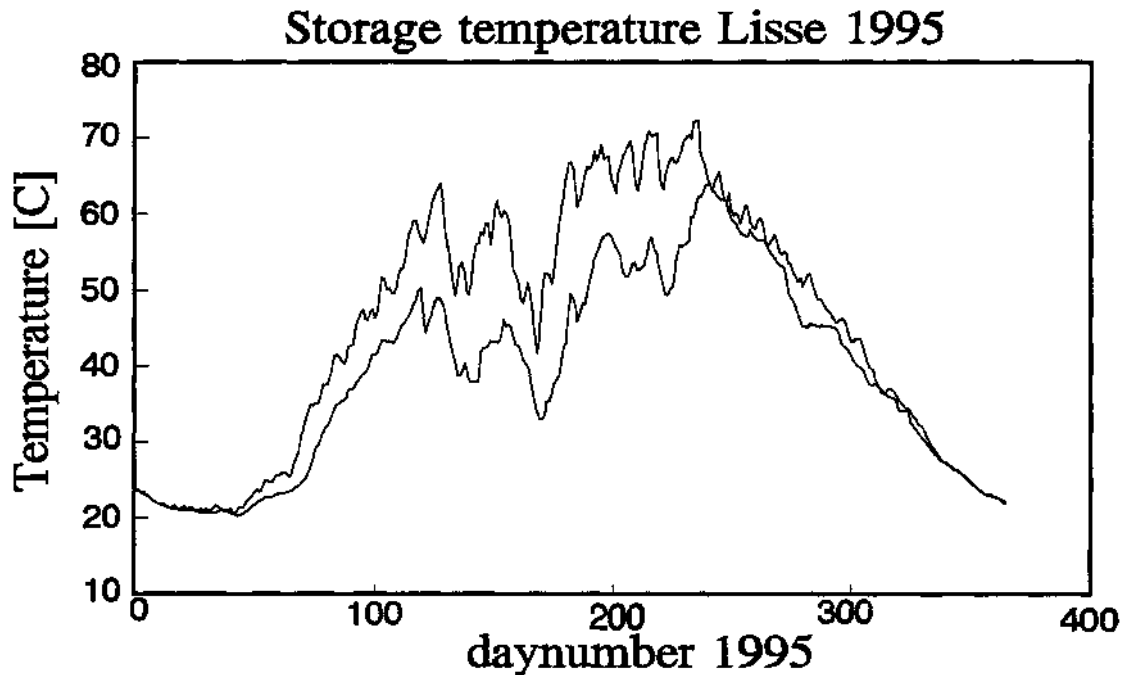
Figure 4.6 Temperatures in the storage during the year.

4.2.3   Collector efficiency

The flow through the collector fields is adjusted at 0.005 Kg/s based on actual measurement in the circuit during the final control. The efficiency of the collector fields for day 180 of 1995 is given in figure 4.7. During 12.00 - 13.00 hour the efficiency is as expected about 60 %. However in the early morning and late afternoon the efficiency drops more then expected. In the figure the time is printed in order to make the time effect visible. After Hour 7 the collectors functions according to the well known collector efficiency curve. Around hour 9 a maximum is reached. Hereafter the efficiency drops till the collectors are switched off in the evening.

Analysis showed a number of effects:
*   shadowing of parts of the field due to the orientation;
*   high switching ΔT;
*   capacity effects;
*   time of the year.

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collector efficiency day 180
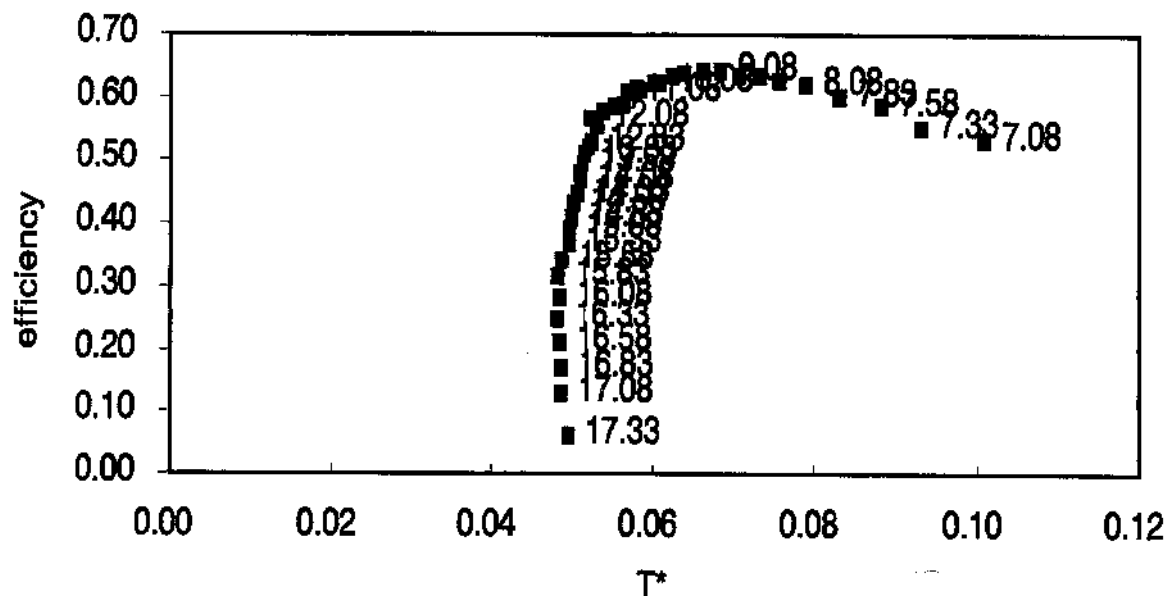
Figure 4.7 Collector efficiency of the field on a typical day.

However these four effects are not the main reason for this typical behaviour. Further analysis showed that the pressure in the collector circuit is much lower then the 3 bar working pressure as originally designed. During 1995 on several occasions the pressure was raised in the collector circuits. However, every time the pressure dropped again, probably due to the securities. During inspection in January 1996 the working pressure was only 1 bar. Further research into the cause and solution for this problem will be carried out during 1996.

4.2.4 The storage

Based on the measurements in the storage tank the average heat loss coefficient is calculated and is (0.6 ± 0.2) $\text{Wm}^{-2}\text{K}^{-1}$. This is somewhat higher then the design value which is 0.35 $\text{Wm}^{-2}\text{K}^{-1}$.
Inspection of the storage showed that a small piece of the top insulation material was fallen of. Due to the missing insulation a vapour-condensation process can take place which increases the thermal losses of the storage.
Further investigations of these effect will be carried out in order to minimize the effects on the heat loss coefficient.

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4.2.5 Heating load

Heat exchangers

During commissioning it appeared that the heat exchanger in the collector circuit was wrongly installed. After correction the efficiency was established and is 90 %. This means a heat transfer capacity of 75 kW/K.

The other heat exchanger is placed between the storage and the drying wall and or floor heating. The efficiency is about 70 % and the heat transfer capacity is 32 kW/K. The flows on the primary and secondary side of the heat exchanger are balanced. The flow through secondary circuit is dependant on the number of preheaters used in the drying wall. Moreover, the secondary flow can be very low if only the floor heating is used. The flow in the primary circuit, however is constantly high. This causes more mixing in the store then expected and a lower efficiency in the heat exchanger. Measures to improve this process will be looked into.

Drying wall

As mentioned before the drying and conditioning process of the bulbs is the critical factor in this type of processes. Therefor the owner controls the temperature, airflows etc. of the drying process very closely. Over time the control schedule changes due to improved insights. Since the solar system and the drying wall are controlled by the same computer, the control strategy is more complex then originally foreseen. Analysis of the use of the drying wall showed that the heat transfer capacity is only 20% of the design value, partly caused by the control strategy.

This lower value causes higher return temperatures in the solar circuit. This means that less energy can be extracted from the store as is available. Improvement of the control strategy and heatexchangers can improve the solar contribution to the drying process.

4.3. ANALYSIS OF THE PROJECT

4.3.1 Pre-design and design phase

pre-design phase

In the pre-design stage the global outline of the system was discussed. Further information on the heat demand and the future needs resulted in the dimensions of the bulb drying system. With this information the feasibility study was carried out. New aspects were advanced collector field with standard collectors and collectors with convection barrier, seasonal storage which is loaded and unloaded two times a year, the combination of the underground storage and the new building.

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Based on the feasibility study a subsidy application for the EU thermie programme was supplied and accepted. After approval of the project the realization phase started in which the final system design was made based on the requirements of the future owner, final cost calculations and pragmatic requirements. On a number of aspect the system was adjusted.

Design phase
Changes in the system design were carried out in order to optimize the lay-out. The most difficult part was as foreseen the construction of the storage.
The requirement that the top of the store should be use as factory floor made a foundation with concrete pilings through the store necessary.
The central computer of the owner will be used for controlling the solar system instead of separated control units. This central computer is, due to the control of the drying process, already available.
To safe costs, there has been decided to feed the collectors with one pump instead of four pumps. This means that the hydraulic connections from the heat exchanger to the three roofs will not be made through an open distributor.
This will cause a much more simplified pipe system, with less pumps and for that reason the costs will be less.
To get a regular wear of the pumps, they will be switched over one by one. Moreover, if one pump fails, the other pump can take over the pumping without causing a total stop of the installation.

Solar energy costs
The cost/performance ratios is given based on the design.
The calculations are based on:
> An investment subsidy level of 50 %;
> a system lifetime of 20 years;
> a yearly interest rate of 8 %;
> Auxiliary efficiency of 60 %;
> Natural gas price of US$ 0.25 / m^3 (7.8 US$/GJ);
> Electricity price of US$ 0.10 / kWh (28 US$/GJ).

It should be noted that the solar energy system means an improvement of the performance of the heating systems in the factory. The natural gas and electricity price are the 1992 prizes in the Netherlands.(Due to taxation (ecological) these prices are rising by 10-20% from 1996-1999.)The price-performance ratios of the solar systems are quite comparable with that of a conventional expansion of the capacity.
In the Appendix C the price/performance calculations are worked out. Based on the predicted solar contribution of 1.77 GJ and a total heat demand of 5.7 GJ the solar energy price is calculated at 14.4 US$/GJ (without subsidy 28.8 US$/GJ).
A conventional heating system which can provide the increased heating demand as foreseen for the future the price for heating is estimated at 14.7 US$/GJ.
Maintenance and operating costs are taken into account.

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4.3.2   <u>Realisation</u>

4.3.2.1   Collector array

In order to protect the collectors against freezing damage, this circuit will be filled with an anti-freeze solution.

The connection of the fields to each other is in series in order to reduce a high pressure drop over the fields (and thus a reduction in pump power)

The collectorfield consists of approximately 60% standard ZEN collectors and approximately 40% standard ZEN collectors with teflon convection barrier.

The collector circuit was filled with water-propyleneglycol and flowrates through the three collector-fields were adjusted. A tank is installed to hold the water-glycol in case the circuit is drained by the action of the pressure-relief valve (a situation that can occur on a sunny day in case the circulation of the collectorcircuit stops due to pump-problems or power failure).

The store charge and discharge circuits gave problems : poor start-up of circulation due to air in pumps. One-way valves are installed and proved effective.

The collector-fields were visually inspected in february 1995. Some observations:

> The seams in the teflon foils in the collectors are ruptured.
> The foil-support structure was designed allowing for this problem, therefore the ruptured Teflon foils are still effectively supported and function as intended.
> Attacked insulation material on piping.
> The neoprene rubber insulation on the piping of the collectors was finished with aluminized polyester tape. Contrary to manufacturer information, the tape is not weather resistant and is replaced by aluminium tubing.
> Minor deformations of the absorbers.
> The absorbers are somewhat deformed due to deformation and expansion of the polyurethane back-insulation. This is caused by the high stagnation temperatures that the collectors had to withstand in a long and hot summer period in which the circulation was switched off.
> This deformation is not enough to affect the performance negatively. From now on this process is stopped, because the continuous circulation of the collectors prevents stagnation and the associated excessive heating of the absorbers and materials in the collectors.

After installation of the complete solar collectorfield including the headers, the system is pressurized and tested for leakages.

4.3.2.2   Storage construction

The construction of the storage turned out to be the most critical and difficult element of the system. Problems in the realisation caused a draw back in the time schedule and therefore the start of the functioning of the complete system.

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In the process of redesigning the storage a separate re-engineering study was carried out by independent experts in order to get as good as possible advice on how to proceed.

Finally, in December 1994 the storage came into operation. There are no indications for leakages detected and first analysis showed a good functioning of the storage. Further analysis will go into the overall heat loss factor. Practical experiences with the complete installation and specially with the storage over the years will give information on the potential of the concept.

The construction of these kind of storages under these typical circumstances should be further investigated in order to get more information on the behaviour of the elements, materials and components.

4.3.2.3   *The rest of the system*

During the analysis of the first measurements the efficiency of the heat exchangers appeared to be low, only 50%. Further analysis showed that the heat transfer capacity was only 14 Kw/K instead of the design value of 108 kW/K. Inspection showed that the heatexchanger was not installed in the counterflow but in the parallel flow configuration. This is corrected.

4.3.3   Analysis of the results

Solar system

The major results obtained by detailed analysis of the measurements in the solar system are the following:

- The collector with the convection barrier are functioning according the specifications.
- The collector circuit functions according to the design. The only practical problem occurs in the low pressure in this circuit.
- The secondary circuit of the solar system appeared to be very critical. This is not only due to the solar system, but also to the variations in the heat demand in the drying process and the floor heating.
- The total solar energy contribution to the process heat is relatively much higher then designed, but absolutely much lower. This is caused by a much lower heating load and lower efficiencies in the secondary circuit and the store.

Storage tank

The unique construction of a storage under the requirements of the project has proven to be extremely difficult and not without technical risks. This project has learned a number of valuable lessons in creating this type of storages under ground water level. The heat loss coefficient is somewhat higher then the design value.

Finally the functioning of the storage agrees good with the design.

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Drying process
The drying process is a very critical factor in this system. Due the interactive character of the control and new requirements for a solar energy system the practical realisation of the control can be optimised. Moreover, the flows in the secondary circuit of the solar system should be better adjusted to the flows in the drying wall and or floor heating. Improvement in the heat exchanger efficiencies can be obtained by fine tuning of the flows. The capacity for the drying process has increased considerably.

4.4 OBSERVATIONS AND PROJECT EXPERIENCE

From the demonstration project in Lisse a lot is learned. To make an advanced solar system work into reality was a hard job. A number of aspects on this project were new and advanced. The manufacturing, installation and performance of improved collectors was successful. The realisation of the diurnal used seasonal storage buried in the ground and suited for a building on top had a long story and delayed the realisation process considerably. In the end the storage functions good.
To fulfil the commitments set at the beginning of the project the heating load of the drying process should be met and the conventional installation parts should function as designed. Both were not met in practise. Due to all kinds of reasons the heating load in the monitored year (1995) is much lower then the design value's. Moreover, the conventional installation technique and starting point are not adjusted to solar energy. Therefore heatexchangers have lower values, temperature levels are too high, pumps are not working optimal etc.
Every time the experience learned that designing and realizing large solar systems asks other knowledge then available in the conventional installation world.

4.4.1   Collector performance

The standard and improved standard collectors are working according to the design values. No specific problems were encountered and the teflon barrier are due to the international collaboration and know-how placed in an effective way. Conventional problems with maintaining the pressure in the collector circuit are encountered and should be solved. Development of large drain back collector circuit are started, since glycol is still a costly part of these installations.

4.4.2   The storage

As mentioned already in the report, innovative construction should be carefully developed. This is clearly the case for the Lisse storage. The strong boundary conditions were hard to met. The seasonal storage must have a very long life time and repair of faults is hard. The design and construction process gave a lot of valuable information. However, it is still questionable if a next seasonal storage of this type can be made based on the now available knowledge.

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If these type of seasonal storage have a future perspective targeted research on a number of aspects should be carried out. This can (of course) best carried out in an international context.

Specific know-how for solar system purpose is time after time hard to find. Watertightness is known, but not for higher temperatures. Insulation material is good known but not for underwater application. These are just two examples.

4.4.3 <u>The system performance</u>

Conventional components influence strongly the performance. The heat exchangers and the control of the drying wall must be improved. The solar system had in the overall heating load a large part. On the other hand the heating demand was much lower then the design value. Conclusions on only 1 year of monitoring are hard to make. A longer period of monitoring is needed to come to full conclusions. In the mean time the flaws in the system can be improved. Moreover, a redesign based on the changes in the drying process and the development of the heating load should be carried out in order to improve the solar output of the system.

In general in part 2 of this report valuable lessons of the large solar system projects are given and should be taken into account for the realisation of future projects.

REFERENCES CHAPTER 4

In general see Appendix C of this report for more information.
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PART 2: GENERAL OBSERVATIONS AND EXPERIENCES

5. OBSERVATIONS

5.1 PROJECT INITIATION

- For a succesfull application of "advanced systems" the customer or targetgroup must be trendsetters; if only economic motives are involved it is difficult to make an advanced project.
- In the first stages a critical approach should be taken for the availability of capital resources, in order to guarantee an successful project.
- Realistic information on technical and financial risks involved must be supplied in a way that the enthusiastic attitude of the partners is not frustrated.
- Selection of contracting partners with an ability to learn from the project is very important.
- carefully analyze advanced concepts and their integration into the overall energy system/scenario of the project.

5.2 FEASIBILITY STUDY

- Make a risk analysis (financial and technical) as part of the feasibility study.
- Be aware of frustrating elements if the risks are stressed and the assets of the project are neglected (keep a positive attitude to the project / but realistic).
- Financial commitments of various parties is a delicate procedure. However unavoidable in this feasibility stage.
- In general subsidies should be avoided as much as possible. They defer ones attention from technical elements of the project in order to meet may bureaucratic demands.
- Be very selective in the number of obligations financial partners in the project might demand. Allow for provisions to absorb possible risks. It is a demonstration project, so this should be in the foreground.
- Check and cross-check the load information of every person/specialist involved in that phase of the project planning i.e. energy, power. power ratings of components, operating-hour-meter/(counter) infos, temperature load profiles:day 24h, sunrise, sunset, week month year.

5.3 DECISION MAKING PROCESS

- Because of the mixed financial input in these innovative projects the structure of the decision making process will be diffuse, because all parties have a different interest in the realisation of the project. This element of the decision making process must be clarified to all parties involved before the final decision will be made.

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- Avoid any conflict of interest between contracting partners and the financial contributors or make very clear distinctions in responsibilities.
- Define a clear line of responsibility for the project. Appoint an overall responsible project manager, with defined authorities.

5.4 FINAL DESIGN

- The final design could lead to a reconsideration of the go/no go decision.
- Allocate enough time for the final design
- Detailed workplan and design is essential before realisation can start.
- No open ends on any technical detail; if necessary do extra technical research to avoid technical risks;
- Advise to have a feedback step to the project initiators and financial supporters of the project.

5.5 REALISATION

- For the collectors with the extra teflon barrier, the international networks has given valuable information that could be obtained in time. It proves the importance of good international contacts.
- Non-proven new technologies should be tested on small scale before large scale applications are estimated. This is especially true for the storage system.
- A large number of technical lessons were learned:
  - storage insulation materials under water and resistant for temperatures up to 80 °C;
  - storage water tightness, especially important in conditions with changing groundwater level;
  - storage pressure on the bottom, materials, temperature distribution through the storage were critical elements during the realisation;
  - piping & collector checks for water tightness and freezing protection;
  - pumps be checked on their flow and design conditions.

5.6 COMMISSIONING

- Allow enough time to check the installation under all kinds of weather conditions.
- Make sure that the control strategy is secured.

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5.7 MONITORING

- Detailed monitoring should be carried out for large systems in order to understand the processes in the system. Frequently, in detailed analysis it appears that knowledge of system interaction is essential for improving the design.
- Simple analysis by means of Input/output correlations should first be used to show failures in the monitoring system or as commissioning tool for the system.

5.8 EVALUATION

- (International) collaboration in the evaluation phase is an effective means in order to discuss flaws and possible solutions.
- Take measure to correct omissions and/or flaws.
- A good working and performing system is an advertisement for solar energy; solar is always blamed if the systems is not performing well.

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6. LESSONS LEARNED

6.1 GENERAL LESSONS LEARNED

6.1.1   Project Planning, feasibility study and design.

Thorough review of the project and load parameters. Confirm the information supplied by third parties by yourself:

Göttingen   — The return temperature of the DH network is still much higher then projected. The realisation of the planned lowering of the return temperature (down to about 40 °C) appeared to be much more difficult and time consuming than projected by the consultant responsible for the operation and maintenance of the conventional part of the DH-network.

Lisse - The actual load figures turned out to be much different from the design figures. Moreover, the future use of the system appeared to have changed compared to the starting points.
Make sure the goals and objective of all parties involved are clearly stated and understood.

Falkenberg -   Make sure the goals and objective of all parties involved are clearly stated and understood

The requirements of financing parties must be compatible with the general objectives of the project.:

Gottingen   — 50% of the total solar investment had been financed by the Federal State of Niedersachsen under the condition, that the return temperature of the network will be lowered down towards 40 °C.

Lisse - An EU subsidy of 40% was awarded, only based on a feasibility study. The innovative and critical system parts are the risk for the project developers. The future system owner and the contributing parties took only minor risks.

Falkenberg -   The collector manufacturer gave guarantees on the improved performance and the installation price.

Confirm new technical solutions on a small scale, before applying into practise:

> Lisse   Storage tank realisation appeared to be difficult.

> Falkenberg -   Stratifying enhancement did not work as designed.

> Göttingen   -   Lowering the return temperature of the district heating system appeared to be difficult.

Guaranteed performance needs to be carefully defined:

> Göttingen   — This project is not part of the GRS programme; but the positive test of the ISFH input/output controller has demonstrated, that this concept is well adapted to check the collector loop operation and to verify the collector yield within an accuracy of $\pm$ 10..15% depending on the season.

> Lisse – The performance given in the feasibility study is not guaranteed for the system realisation. Since the solar contribution is heavily influenced by the drying process this should be an essential part of the definition. Therefor more knowledge is needed on the energy and temperature dependence of drying processes.

> Falkenberg - The project was turn-key. The project had to fulfil well defined goals as a lower price for the same performance. Therefore the cost must be kept as low as possible and on the same time minimise the risks of malfunctioning. The advanced items were not included in these commitment.

The risk of corrosion in storage tanks should be seriously considered:

> Lisse   - Concrete underground tank, no corrosion problems.

> Falkenberg - The steel tank is unpressurized and the water surface moves to allow for the expansion of the water. To avoid an inflow of oxygen and as result corrosion, a small additional pressure is maintained over the surface by means of a water-lock and a steam boiler. However, this solution did not work properly.

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6.2 TEFLON APPLICATION

Although the application of convection barrier films is not new, the lessons learned in the past have generated some general guidelines for this purpose.

Both the Falkenberg project as well as the Lisse project made the application of convection barrier films to one of the improved options in the project.

In case of the Falkenberg project a Teflon foil has been mounted by a special spring construction to keep the material stretched. In Lisse the FEP-film was mounted between a net of stainless steel wires in order to prevent tearing (caused by stretching) and sagging to the absorber or adherence to the glass.

The visual appearance of collectors with these films is not always appreciated, although in time it appears to improve caused by a slight shrinking of the material as a result of temperature cycles.

In many circumstances the use of convection barrier foils have caused problems. These are mainly:
- Tearing
- sagging (touching the absorber)
- adherence to the glass cover (presumably caused by static electrical effects)
- delamination of the welding
- relaxation (appears to be related with the thickness of the foil and/or the manufacturing process. Although this effect did not occur in these project, relaxation did occur in other collector developments).

The possible causes for problems can be traced to the mounting technique of the foil in the collector.

The two projects (Falkenberg and Lisse) have generated information concerning these typical problems. However it must be stressed that experience over time must proof long term reliability.

In both projects foils have been used with a thickness of 50 micron.

In the Lisse project FEP-film has been used which has a temperature stability of -200 - +200°C.

The two projects used a different approach of mounting the foil in the collector. The Falkenberg project mounted the foil by special profiles along the end of the absorber, stretching the material. Based on the Falkenberg experience the foil in the Lisse project was not stretched, but mounted without tension between a net of stainless steel wires.

Lessons learned, related to the specific problems:

If the foils are mounted under tension using some spring construction, in order to prevent the material to sag to the collector or to stick to the glass, it is extremely important to take every precaution that there will be no sharp part in the clamping construction or any perforation in the film. In particular the situation in the corners turned out to be very vulnerable.

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One way to reduce the chance of tearing is by mounting the film, without tension, between two nets of stainless steel wires. The film is fixed to the sides of the collector casing and is kept in position by a net of steel wires underneath the film (to prevent sagging) and on top of the film (to prevent sticking to the glass).

The wires used in Lisse were: stainless steel 1 mm, spaced at 23 mm underneath the foil and 600 mm on the top side of the foil.

If the foil needs to be welded, it is important to access the best possible welding technique. Depending on the possible tension in the material it is recommended to choose either a "butt-welding" (high strength in tension), "overlap welding" (medium strength in tension) or "lay-flat welding" (low strength in tension). Obviously the cost of the welding technique increases with the strength in tension.

If the seizes of the foil do not match with seizes of the collector, it is recommended to consider a vertical (oversized) overlap instead of a welding.

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6.3 CASE STUDY: THE LISSE STORAGE DESIGN (The Netherlands)

The heat storage as part of the solar energy system for the bulb drying plant, had to be specificly designed. The special requirements of the storage, as well as the specific soil conditions and groundwater level didn't allow for a standard construction.
The storage had to meet the following requirements:
- ■   storage capacity: approx. 1000 m^3 of water
- ■   temperature resistance 25°-80°C
- ■   the top of the storage to be used as factory-floor
- ■   durable insulation on all sites of the store
- ■   no water leakages in-or out the storage

The construction of the storage turned out to be the most critical and difficult element of the solar energy system for the bulb drying plant.
The complicated soil and groundwater situation, in combination with the requirement of a construction to be used later as part of a factory building with the specific criteria for foundation, turned out to be a very complicated matter.
Apart from this the lack of experience with HDPE-liners for this type of constructions and the requirement of high temperature resistance made the construction a high technical risk.
To complete the already difficult construction, the first law of Murphy was applied to this storage (:"everything which can go wrong, will go wrong").

Special attention for the construction was caused by the fact that the groundwater level will vary between 0.6 and 1.0 m[1] below ground level.
This condition will make the storage a floating vessel during construction and/or maintenance situations, with an actual danger of raising of the tank.
Apart from this the requirement, the top of the storage should be used as factory floor which made a foundation with concrete pilings through the storage tank unavoidable.
The original construction design was followed. The concrete piling were put in place. The foundation beams (for the factory) were constructed and the steel sheet piling were drilled. These sheet pilings were welded to a complete watertight wall-construction after the pit was dugout. The pit itself was kept dry by pumps. A water tight layer of clay approximately 2 meter below the bottom of the pit prevented the sand bottom to burst. The bottom of the pit was approximately 2.5 m below the groundwater level.
The required temperature range allowed polystyrene insulation material as the main insulation to be placed on the inside of the construction.
A high-density polyethylene foil (HDPE-foil) of 3 mm would guarantee a 100% water proof liner in the storage.

Unfortunately the power supply failed (this is were Murphy started) the moment the concrete was poured for the base/floor construction. As a result the pumps failed and the ground water level gradually raised, dissolving the fresh concrete on its way up and permanently destroying the watertight connection between the concrete floor and the steel sheet pilings.

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In order to repair the damage, a steel boxing had to be applied, creating again a water tight construction.

The PS-insulation was applied to the walls and floor. On top of this the HDPE liner was put in place. A pumping device was installed between the steel boxing and the HDPE-liner. This should enable the water, penetrated in the insulation material, to be pumped out of the construction.

Once the storage was filled for the first time it turned out that the HDPE foil, although carefully welded, applied and guaranteed was not water tight. Water was leaking through the foil, into the insulation layer and finally created a volume exceeding the pump capacity. As a result the insulation material located at the bottom of the storage at approx. 2.5 m[1] under the water level started to float, destroying the HDPE-foil.

At this point in time the storage was redesigned, using Foam glass as the main insulation material and a bonding the HDPE foil as an appropriate solution.

Later, as some calamities occurred, the construction design was changed.
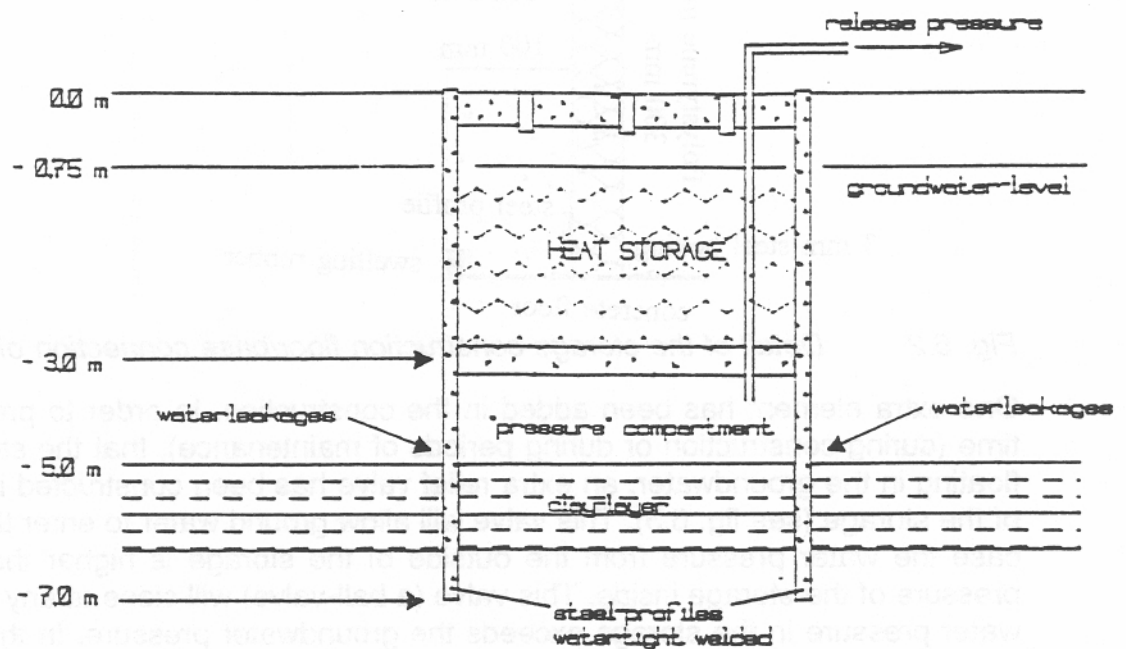
Fig. 6.1   Cross section of the storage tank construction in Lisse

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These changes are based on a study [see Appendix C]. The inside of the storage was lined with steel sheets, welded to a complete water proof construction (called boxing). The walls of the steel liner have been insulated with Foam-glass board. The Foam glass was applied to the steel walls, using a glue called PC-88. Based on the manufacturers information it became clear even Foam Glass would have durability problems with exposure to water with temperature of up to 70 °C. Therefor on top of the foam glass a special water- and temperature resistant PC-coating (PC-88) was recommended and applied.

The base or floor of the storage has been insulated with polystyrene insulation material. The degradation of the U-value of PS, caused by water saturation in the polystyrene has been compensated by increasing the thickness. In order to prevent the polystyrene to float a concrete ballast slab has been set over the floor insulation. In figure 6.1 the cross section of the construction is given. Moreover in figure 6.2 a detail of the storage construction around a concrete pile is given.
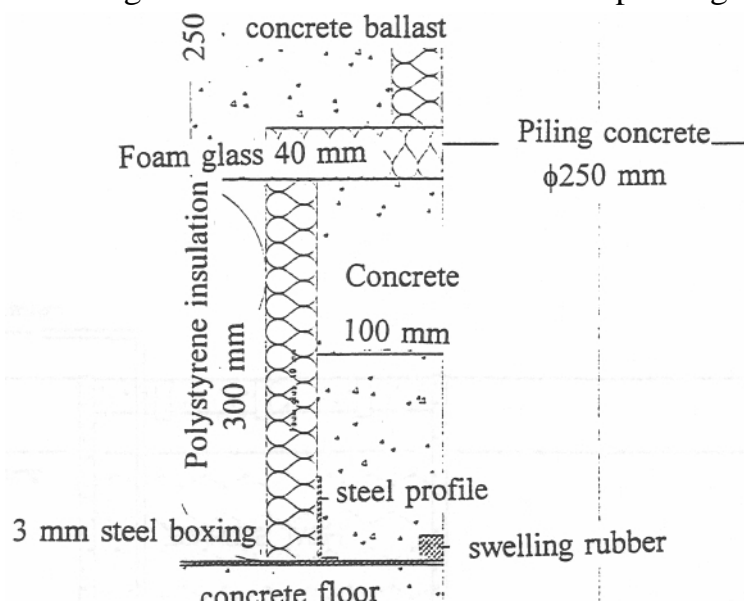
Fig. 6.2   *Detail of the storage construction floor/base connection of pilings*

One extra element has been added in the construction. In order to prevent, at any time (during construction or during periods of maintenance), that the storage will be floating in the groundwater, an extra relief valve has been constructed in the bottom of the storage (see fig. 6.3). This valve will allow ground water to enter the storage in case the water pressure from the outside of the storage is higher than the water pressure of the storage inside. This valve (a ball-valve) will close at any time that the water pressure in the storage exceeds the groundwater pressure. In this way water can only enter into the tank, while leaking through the valve is excluded.

Extra attention had to be paid for the connection between the concrete piling and the floor. Special water-tight rubbers have been applied in order to make this part of the construction leakage free.

The final design showed the following parameters, given in table 6.1.

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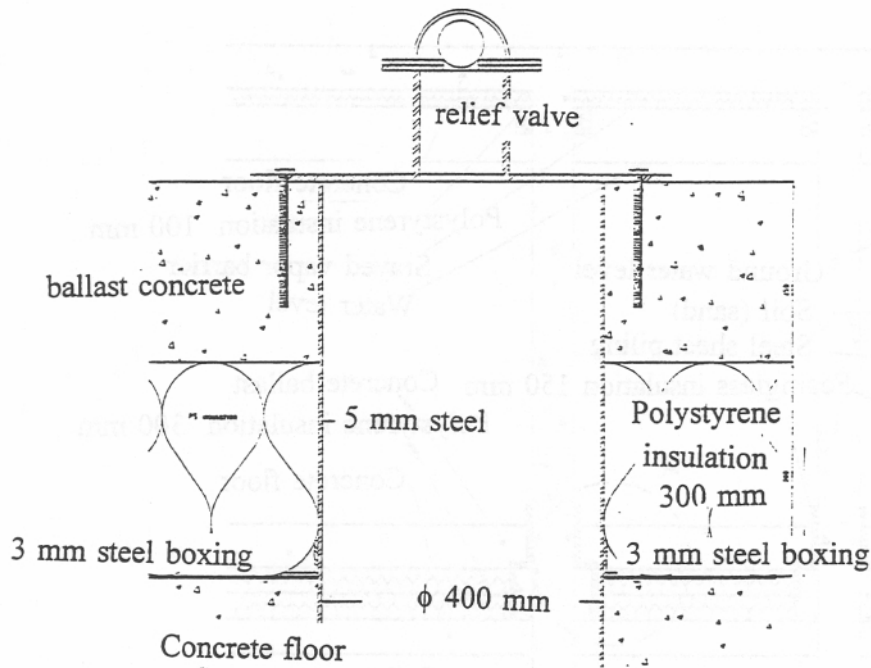
Fig. 6.3   The relief valve of the storage tank

Storage content	1000 m³
Seize	20 x 20 m
Height of the storage inside	3250 mm
Wall insulation	Foamglass 150 mm
Coating on wall insulation	PC 88
Floor (base) insulation	PS 300 mm
Floor ballast	Concrete 250 mm
Top insulation	PS 100 mm

Table 6.1   The parameters of the final design of the storage.

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Concrete floor
Polystyrene insulation 100 mm
Srayed vapor barrier
Water level

Ground water level
Soil (sand)
Steel sheet piling
Foamglass insulation 150 mm

Concrete ballast
Polystyrene insulation 300 mm
Concrete floor

A

Soil (sand)

Soil (clay)

Fig 6.4   Schematic presentation of the realised storage

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6.4 TO LOWER THE RETURN TEMPERATURE OF A DISTRICT HEATING NETWORK

In solar district heating a low temperature level and a large difference between the supply and the return of the district heating (DH) network improve the performance both of the solar heating and the DH system.

The efficiency of solar collectors increases considerably with decreasing working temperature. Furthermore, a low flow rate in the collector loop offers cost advantages. To make full use of the large temperature rise supplied by a low flow collector loop the temperature drop between the DH supply and return needs to be as large. Simplified, the collector should deliver the temperature required by the load, but not higher. The heat should then be delivered to the load with a minimal drop in temperature. The return temperature of the load should be as low as possible and the temperature rise to the collector supply temperature should be minimal. If not, the collector loop operates at a higher temperature level than necessary. Lastly, the part load performance of the heat distribution system is critical to the solar heating plant since it operates mainly when the DH load is small.

To the DH network a lower temperature level means lower heat losses. A larger temperature difference may be exploited to increase the capacity of the network, to decrease its losses by using thinner pipes, or to decrease the pumping power. Furthermore, a low temperature level in the district heating network is beneficial to heat pumps, co-generation plants, exhaust gas recovery boilers, use of surplus heat, etc.

The Göttingen and the Falkenberg projects, which both apply solar district heating, include systematic efforts to lower the return temperature in existing DH networks. In this section we outline a tentative approach based on our experiences from the Falkenberg and the Göttingen projects. These projects are reported in Chapter 2 & 3, or more in detail in Appendices B & C. In existing district heating systems like these two there are large potentials to lower the temperature level and to increase the difference between the supply and the return. Some reasons to this state are obvious. Boilers present little incentive to keep the temperature low. They rather require a high temperature level to improve the combustion and avoid condensation. In space heating high flow rates and temperature control by use of bypass and mixing valves make up robust systems. Furthermore, when introducing district heating in areas with existing buildings a utility company might be inclined to adapt the DH network to the installations of the customers. The cost to adapt these installations to a lower temperature level would add to the large investment of the district heating network itself. Mostly the consumer installations were originally supplied with heat by small boilers and thus they are typically designed for both a high temperature and a high flow rate. Moreover, the DH supply temperature must satisfy the requirements of the customer requiring the highest temperature. There are good reasons to apply low temperature techniques in new DH networks. Firstly, there are the advantages mentioned above. Secondly, it facilitates a future introduction of alternative energy sources. Lastly, there is a technical potential to build a less expensive network by applying a lower maximum temperature and thus a lower maximum pressure in the system.

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6.4.1 From the solar heating point of view

Solar district heating requires low temperatures in the DH network, especially low return temperatures in the summer season. On the other hand, heat pumps and co-generation plants require low temperatures during the heating season, as does solar heating plants with seasonal storage. Thus, to lower the DH temperature for solar heating might require somewhat different technical solutions.

In theory it is straightforward to devise a DH network for a solar heating plant. Thus, the goal is to produce heat at the lowest useful temperature and transfer it to the point of use with a minimal temperature decrease. The principles of low flow solar heating systems are applicable. Firstly, heat is effective at the point of use only if it is available at a high enough temperature level. This critical level depends on the type of load and the technical system. Moreover, it typically varies with time. Theoretically space heating may be accomplished using heat somewhat above the indoor temperature level, and water may be heated from 10°C to 60°C using heat at an average of 35°C. The basic items of low flow solar heating are:

- Heat exchangers with balanced counter flow.
- Storages with temperature stratification.
- Large temperature difference between supply and return. The difference between the domestic hot water and the cold water temperature indicates an appropriate target.
- Mixing of water of different temperatures should be avoided.

6.4.2 Service water heating

To the solar heating plant the performance of the service water heaters is vital since in the summer season a large part of the total DH load is service water heating. The demand for hot water is fairly constant over the year, but it varies widely over the day. There is typically a peak in the morning and a very small demand in the night. Figure 6.5 shows a schematic of a storage type service water heater that applies the basic ideas of low flow solar heating. Compared to conventional designs, the main difference is that tepid water returned to the tank by the hot water circulation circuit (HWC) is used to prepare hot water (HW). This hinders tepid water from reaching the bottom of the tank and thus the heat exchanger.

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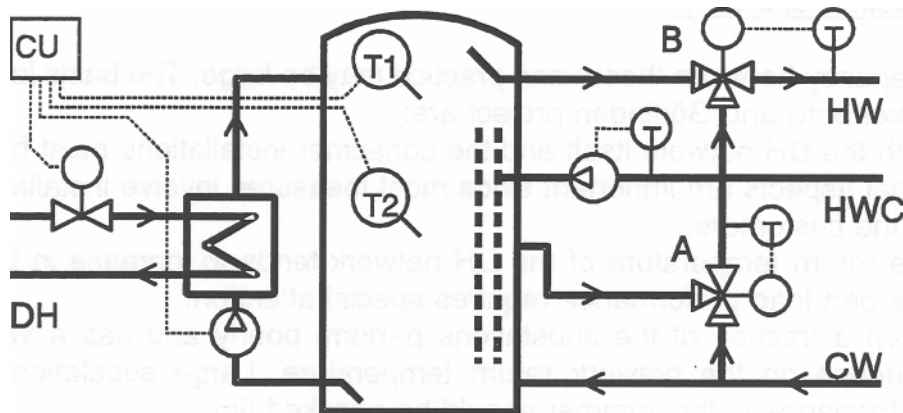
Figure 6.5 Schematic of a tentative storage type substation for service water heater. A low primary flow ensures a large temperature drop. The volume is divided into three zones: an upper hot, a middle tepid and a bottom cold zone.

The flows through the counter-flow heat exchanger are small and balanced. In the summer season the DH supply temperature should match the hot water temperature. The tank contains three zones: an upper hot zone, a middle tepid zone (temperature of the HWC return), and a bottom cold zone. The boundary between the hot and the tepid zone moves between the sensors T1 and T2. The extent of the tepid zone depends on several factors. It will decrease during periods of large load and increase during periods of small load. With proper dimensions the tepid zone will seldom reach the bottom of the tank. Thus, the return temperature on the DH side will mostly be close to the cold water temperature. The low flow rate and as a result a low charging rate yields a long operation time and thus an effective use of heat exchanger. There is a trade-off between charging rate and storage size.

A prime goal of the supply side circuit is to maximise the use of water from the tepid zone to prepare hot water. The mixing valve (B) limits the hot water (HW) temperature to a pre-set value (scald protection). Furthermore, the inlet of the HWC circuit requires special attention not to cause mixing in the tank. Here a small flow from the top of the tank keeps the HWC-circuit warm. The flow is just large enough to keep the return of the HWC circuit at a pre-set temperature value. Moreover, the return flow from the HWC circuit is fed into the tank via a perforated manifold, which brings the flow to search the level in tank, the temperature of which agrees with that of the flow.

The instantaneous type substation is the prime choice when a continuous supply of hot water is required. Here the flow rate on the primary side needs to be controlled by the flow rate on secondary side. When there is no hot water demand the return flow from the hot water circulation circuit presents a problem. There is nowhere to bring it without affecting the return temperature on the primary side. Moreover, when the DH supply temperature is below approximately 70°C a large heat exchange capacity is required to meet peak loads.

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6.4.3 Practical approach

The discrepancy between theory and practice may be large. The basic lessons learnt in the Falkenberg and Göttingen project are:
- Both the DH network itself and the consumer installations must be tackled.
- Legal aspects are important since most measures involve installations owned by the customers.
- The return temperature of the DH network tends to increase in the summer. The part load performance requires special attention.
- Often a fraction of the substations perform poorly and has a very negative influence on the network return temperature. Large substations with poor performance in the summer should be attacked first.
- In an existing district heating network it may be both costly and laborious to lower the DH return temperature

Thus, one need to approach the work in a systematic manner. The overall task may be divided into following subtasks
- On-site survey and up-dating of the documentation of the substations and the consumer installations
- Analysis of the thermal performance of the substations based on available data
- Supplementing measurements as needed.
- Design
- Realisation
- Evaluation
- Operation

6.4.3.1 On-site survey of the installation

The documentation of an existing DH network and the consumer installations will most likely not be up-to-date. Furthermore, the systems often do not work as intended due to erroneous settings of control units.

The equipment of the consumer installations needs to be identified and inspected down to the most remote mixing valve. Control curves, setpoints, and actual values of flows and temperatures should be noted. Motor driven valves, etc. should be assessed for reuse. Service water heaters need special attention. Devices requiring especially high temperatures should be noted.

Short-cuts between the supply and the return may appear in unexpected places. In a disconnected substation of the network at Falkenberg one found an open valve that let a large flow directly through from the supply to the return. In another DH plant a large flow was used to heat heavy oil. The circuit was not documented and a revamp decreased the return temperature of the total network by several degrees.

This first step of the project should deliver
- Up-to-date documentation of both the DH network and the consumer installations
- Technical description of the intended operation of the substations and the

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consumer installations
• Description of the actual operation - discrepancies compared to the intended operation.
• Lists of equipment suitable for reuse

6.4.3.2 *Temperature statistics of the substations*

The return temperatures of the different substations will typically span a wide range. At Falkenberg in 1989 the extreme values of the yearly difference in temperature between supply and return were 43.4°C and 5.1°C, respectively. The latter figure originates from a large substation. The energy weighted average for all substations was 20.5°C. The Göttingen DH network exhibits a similar pattern, and there a substation exhibited an average temperature drop of only 0.8°C during July and August 1995. Obviously, the prime efforts should be directed toward substations with high return temperatures and large loads.

Historic data on the load of each substation are often available since the utility company charges the customers based on their energy consumption. The Falkenberg utility company uses heat meters, which record both energy and volume. They record monthly data for both these quantities for all large substations. Presented in a "Substation-energy-share Histogram" as done in the Göttingen project these data provide a compact picture of the situation. Furthermore, one should carefully analyze the differences in the quantities of heat and water delivered from the central plant to the sum of those quantities recorded at the substations. The differences are certainly susceptible to the inaccuracies in the measurements. However, a difference in the volumes might indicate a short-cut between the supply and the return.

For most of the substations the actual behaviour will be evident from the documentation and the on-site inspection. However, in special cases supplemental monitoring during a few weeks might be needed. Walletun [6.1] reports on a tool to analyze the thermal performance of a substation. It consists of a portable PC, a datalogger, and a detailed substation simulation model. He states that with this tool a check of the performance and adjustments can be done within one visit of the substation.

This step of the project should deliver
• A table with yearly data for each substation. The table ought to cover the energy consumption, the volume, the temperature drop, and the maximum supply temperature required by any single device.
• Similar tables for the solar heating season, e.g. April through August, and the holiday period, respectively.

6.4.3.3 *Design*

When the performance of a solar heating plant is the prime reason to lower the temperature level of a DH network the focus should be on the conditions during the summer season. Then the space heating load is small and service water heating is more important. The system operates at part load and in principle a DH supply temperature as low as 65°C would suffice.

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The return temperature of a service water heater could easily be around 20°C. Nevertheless, at Falkenberg the monthly average return temperature exhibits a peak of 60°C in the middle of the summer.

The first task of the design is to establish targets for the supply temperature and the flow rate of the DH network. In Göttingen one achieved a substantial decrease in both the supply and return temperatures (from very high levels) by replacing steam producing devices at a few customers and subsequently changing the control strategy from fixed to variable supply temperature. In a Swedish DH system with a solar heating plant the utility company replaced in residential building convective dryers for laundry by electrical units. Moreover, flow control is needed to achieve a low return temperature in the summer season.

To make the substation return a low temperature to the DH network each circuit connected to the substation must return a low temperature. That is possible only if the subcircuits and equipment connected to these circuits return low temperatures. To achieve this one need to apply variable flow control throughout all the circuits connected to the substation. The Falkenberg report includes some examples of measures. Lastly, the flow rate on the DH side should be controlled by that on the load side.

The supply temperature required will vary between the substations. That cannot be avoided. However, the return temperatures of the substations, which would be served by a lower DH supply temperature, should be cut down by decreasing the DH side flow rate as much as the supply temperature on the load side allows.

There are some situations in which one need to violate the rules. A continuous circulation of warm water might be needed to avoid freezing of air heaters, to ensure prompt supply of hot water in remote part of buildings, etc.

In many cases the actual space heating load is considerably lower than the design load. Firstly, designs are often based on overestimated loads. Secondly, energy conservation measures might have decreased the load. Thus, the radiator area is typically large enough both to increase the temperature drop over the radiator circuits, and to lower the temperature level compared to design values. To take advantage of the large radiator area one need to decrease the flow rates and apply flow control, which in turn might require adjusting and balancing of the flows in the entire radiator circuit. The latter may often be justified by energy savings. It narrows the range of the indoor temperatures throughout the building and thus it makes it possible to lower the average indoor temperature.

Deliveries

•   Draft and description of the revamp
•   Description of adjustments and control settings

6.4.3.4   *Realisation*

Only a few problems from the realisation phase are reported from the Falkenberg project. Some converted circuits generated system noise because the pressure developed by the pump was too high. Possibly, of the same reason some leakage occurred.

6.4.3.5   Evaluation

An evaluation must follow the revamps and the adjustments of the consumer installations. At Falkenberg the immediate results of the first revamp campaign were somewhat meagre. An analysis of the monthly energy and flow rate data, which are acquired routinely, showed little improvements regarding half of the revamped substations. On-site inspection and adjustments solved most of the problems. However, during a subsequent campaign to lower the return temperature one found revamps not made according to the design. The probability of mistakes is evidently much larger when revamping an old system than when installing a new one.

One should make an on-site inspection of the installations and the set points together with an analysis of some measured data. The integrated heat and flow values from the heat meters appear to be a minimum. It is instructive to present these data in the "Substation-energy-share Histogram" presented in the Göttingen report (fig. B.24, B.25). Deliveries:

•   Operating manual for the consumer installation. The operating personnel need adequate instructions on the operation of the consumer installation.
•   As built drawings

6.4.3.6   Operation

The low return temperature achieved by revamp and adjustments will not remain low by itself. Checks and adjustments must be made on a regular basis, since the performance may easily deteriorate. For example, a control valve in the primary return of a service water heater that does not close properly will yield a high return temperature. However, the user will not notice the problem since the supply of hot water will not be affected. Furthermore, problems in the supply causing user complaints might be solved by changing the control settings in a way that increases the return temperature.

A good co-operation between the customer and the utility company is required to maintain the performance of the substation and the consumer installation. However, there might not be any incentives for the customer to contribute. Walletun [6.1] provides Swedish examples where the utility company tries to provide incentives. In at least thirty DH systems the utility company charges for the primary water flow. In one case one charges 0.15 USD/m^3. Furthermore, he reports on examples where the utility companies develop programs to survey consumer installation and to propose measures. A prime purpose of these measures is to decrease the energy consumption and the peak load.

Data from the substations should be monitored to see trends and uncover adjustments of control settings or other modifications. A presentation of the integrated heat and volume values from the heat meter on a substation basis appears to be a minimum. These data should be communicated to the customer. Again the "Substation-energy-share Histogram" presented in the Göttingen report may be used to present the overall status of the DH system.

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6.5 COMMISSIONING PROCEDURE

commissioning procedure for large collector loops

PHASE 1

- Visual inspection
- Pressure test of the circuits
- leakages — yes — fix
  - no
- Fill the system with collector fluid
- Run the system for a few days
- Check on leakages
- leakages — yes — repair
  - no
- Stagnation test
- Check on fow distribution and balance
- Check on control functions and strategy
- Check other safety features pumping (standby, freezing, etc.
- Approved — no
  - Yes

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commissioning procedure for large collector loops

PHASE 2

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7.   **CONCLUSIONS**

The realisation of large solar energy systems is a complex matter. Solar energy installations have high demands on installations techniques and temperature levels in the conventional part of the installation. In all three projects this appears to be difficult to overcome. The communication between solar engineers and conventional installers and designers is a very important issue for which enough time must be taken.

Large improvements in performance/cost ratio's are well possible showing that the solar techniques are just starting. The system designs are tailor made, also the integration with the conventional installation. At the interface between the solar and conventional installation a lot of improvements(price and performance) can be made and are realized. Therefore an integral design appraoch is well recommended.

International collaboration is very valuable for exchange of know-how on specific topics considering solar components and system design. Because of the high cost concerned with a good development of systems and system components this collaboration is extremely important. The framework of the lEA Solar Heating and Cooling programme offers a well established and well functioning umbrella for this.

When (large) solar systems are not working according to the design predictions, the solar part is always the first part which is in doubt about its functioning. Because the relative new technique and the lack of knowlegde about the functioning of solar systems at the level of installers, owners and public the conclusions is quickly drawn about the cause. A bad name for solar installations is difficult to erase. Through a thorough design process, for the complete system, this bad name must be avoided.

From project initiation to realisation and evaluation a good co-operation with the custumer is extremely important.
All parties involved in the realisation of a project must thoroughly understand the complete system. There are risks involved, uncertainties, practical boudary conditions and murphy laws. This means that an open management structure should be created in order to make the responsibilities transparent.

Instructions on the installation for the future owner and customer must be a part of the project. From the start of the project training for the operators, based on good manuals shouls be taken into account. Moreover, the operators will give practical information which should be implemented in the realisation of the project.

Large systems should have a basic monitoring system. The energetic analysis of the system will offer large possibilities to adjust the system during commissioning.
The monitoring period should be long enough to determine the functioning of the system in all modes. This means for large systems normally monitoring periods of 2-3 years. Evaluation should be carried out to learn about the system and its design to realisation process. Moreover, the evaluation offers a good chance to adjust installation parts and the control towards optimal functioning in the realised practice.

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PART 3: APPENDICES

appendices to final report

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LARGE SYSTEMS WORKING GROUP

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APPENDIX A: PROJECT DESCRIPTION OF THE FALKENBERG CSHP-PROJECT (SWEDEN)

CSHPDS
Central Solar Heating Plant with Diurnal Storage at Falkenberg

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A.1 Summary

An experimental Central Solar Heating Plant with Diurnal Storage (CSHPDS) is connected to the heating plant in the district heating (DH) system of the small town, Falkenberg, Sweden. The CSHPDS includes a ground-mounted flat plate solar collector array of 5500 m^2 and an insulated steel tank containing 1100 m^3 of water. The two are connected by a 720 m heat distribution pipe. The heating plant comprises two wood chip boilers and two natural gas boilers.

The district heating system and the CSHPDS are owned and operated by the local utility company Falkenberg Energi AB. The yearly heat production is approximately 100 TJ , which is delivered to 73 substations connected to the network.

The solar heating plant performs well. It has been in operation and monitored since January 1990. During the three years 1990, 1991, and 1992 the yearly average of the solar heat delivered to the district heating network was 5.2 TJ (1.01 GJ/m^2) , which makes up six per cent of the total heat delivered. During a few days in the summer the solar heating plant carries the total load. The monthly solar fraction exhibited its highest value sixty per cent in July 1991.

TeknoTerm AB built the solar heating plant as a turn-key project. The collector used is the 12 m^2 TeknoTerm HT, which is basically of the same design as the one used of the Nykvarn I plant, which was erected in 1985. At that time the Nykvarn I plant manifested a substantial decrease in cost of solar energy compared to earlier plants of this type.

At Falkenberg the investment cost per yearly MJ from the CSHPDS was 0.31 USD (Price level of February, 1989. 1 USD = 7 SEK). This was a twenty per cent reduction compared the CSHPDS of Nykvarn I. A comparison based on the sole collector array shows an equal large cost reduction.

The return temperature of the DH network at Falkenberg was rather high due to consumer installations not designed for low return temperatures. In order to improve the working condition of the solar plant half of the consumer installations were modified. A considerable decrease of the DH return temperature was achieved by revamp and adjustments of the consumer substations and local networks. The investment cost to lower the return temperature was 0.09 USD per yearly MJ (February 1989, 1 USD = 7.0 SEK).

A.2 Introduction

A.2.1 Large collector arrays in Sweden

The conditions for solar heating in Sweden are somewhat special. It is true that the yearly solar insolation in Sweden is comparable to that in Europe north of the Alps, but the mismatch between solar insolation and load is more severe. Due to the northern latitudes there is more solar insolation in the summer and less in the winter. Thus, in Sweden seasonal storage is a prerequisite to a significant use of solar heat. In Sweden we have a fairly long tradition of centralised heat production for buildings. A large part of the buildings in urban areas is supplied with heat from hydronic district heating systems operating at fairly low temperature levels. Furthermore, in Sweden the cost of land in the outskirts of urban areas is moderate. Accordingly, central solar heating plants, solar collectors mounted on ground, and seasonal storage plays a major role in the Swedish R&D activities in Solar Heating.

Central Solar Heating Plants with Diurnal Storage (CSHPDS) are developed parallel to plants with seasonal storage (CSHPSS). The two types share a large part of the technique and since full-scale experiments are less costly to perform with CSHPDS a series of such plants have been built. One objective is to support the development of large ground-mounted collector arrays. In Sweden a CSHPDS will deliver heat during the summer season, and may cover some 10% of the yearly district heating load.

Table A.1 lists all large ground-mounted collector arrays built in Sweden. In 1982 the first collector array consisting of 12 m^2 modules was taken in operation in Torvalla. That plant represented a major reduction in installation cost and some improvement in performance. The following step was taken in the Lyckebo project, which primarily was a full-scale experiment with a seasonal storage. The plant comprises a water-filled 100,000 m^3 rock cavern, a 4320 m^2 collector array, and an electrical boiler.

The plant at Nykvarn was erected in 1985 and is the first full scale CSHPDS built in Sweden. It includes a 4000 m^2 collector array and an above-ground unpressurized steel tank with 1500 m^3 of water. The installation cost was further decreased and the performance was increased compared to previous plants (Isakson, 1990, Hansson and Isakson, 1989). The next CSHPDS was built at Falkenberg in 1989. The plant at Nykvarn was enlarged to a total of 7500 m^2 in 1991. All the arrays mentioned consist of 12 m2 collector modules designed by TeknoTerm AB using SunStrip absorbers and convection barriers of Teflon film. The collectors in these plants compose steps in a successive development.

An array with site-built collectors was erected in Säter in 1992. The 1250 m^2 collector array is connected to the district heating system without a storage. This plant was designed and built by Solsam Sunergy AB.

It is difficult to make an exact comparison between prices of collector arrays in different plants. In some cases the array was bought as a separate entity, in other as a part of a complete plant. Furthermore, the projects use different practice to report on costs. However, the prices reported in Table A.1 refer to an operational array with a heat exchanger in one corner. We added the data on Odensbacken.

Table A.1. A series of large ground-mounted collector arrays has been built in Sweden during the period 1982 - 1992. The total aperture area of the arrays varies between 600 and 5500 m². Two collector types are represented. HT12 denotes the collector module TeknoTerm HT and its predecessors. LGB denotes a collector of Solsam AB built on-site in units that typically are 50 m or longer. The prices shown are recalculated to reflect the price level of December 1991. The value added tax is not included. Source: Zinko and Dalenbäck, 1993

Site	Year	Area, m²	Type	USD / m²
Torvalla	1982	2000	HT12	453
Lyckebo	1983	4320	HT12	496
Ingelstad 1b	1984	1425	HT12	496
Nykvarn I	1985	4000	HT12	363
Ingelstad 1c	1987	1000	HT12	520
Malung	1987	600	LGB	313
Falkenberg	1989	5500	HT12	237
Nykvarn II	1991	3500	HT12	263
Odensbacken	1991	932	LGB	209
Säter	1992	1250	LGB	236

A.2.2 The Falkenberg project

The project at Falkenberg is part of the Swedish R&D effort to develop large solar heating plants.

A.2.2.1 Objective

The main objective of this project was to demonstrate a substantial cost reduction without sacrificing in performance compared to the plant of Nykvarn I.

A.2.2.2 Organisation

The district heating system and the CSHPDS are owned and operated by the local utility company Falkenberg Energi AB.

The Monitoring Centre for Energy Research at the Chalmers University of Technology is responsible for the monitoring and evaluation.

The project is the Swedish contribution to the IEA SH&C Task 14 Large System Group.

A.2.2.3 Realisation

The solar heating plant was built by TeknoTerm AB for Falkenberg Energi AB. It was a turn-key project with ordinary commercial conditions and a special guarantee regarding the thermal performance.

The National Council for Building Research financed the plant by a special loan to Falkenberg Energi AB. The loan is designed for full-scale experimental plants in the field of energy conservation and it covers the total investment cost.

A.2.3 Falkenberg

Falkenberg is a small town with twenty thousand inhabitants situated on the Swedish west coast (N56°54', E12°30') one hundred km south of Gothenburg.

A.2.3.1 District Heating

In the central part of Falkenberg district heating (DH) services commercial buildings and 1200 households in apartment buildings. The total DH output is 13 MW and the annual energy delivered is approximately 100 TJ.

The DH system built in 1985 now replaces the former boilers in 53 block heating systems, most of which were designed to work at higher temperature levels. These systems are owned by the consumers and when connected to the new DH system no measures were taken to decrease the operating temperatures. Thus, the resulting DH system includes a modern primary network and several secondary networks of various standards. The return temperature of the DH network was fairly high, around 65°C during the summer season of 1987.

To improve the performance of the solar heating plant a major effort to lower the return temperature was undertaken. Thus, during the first two years of operation of the solar heating plant the return temperature has decreased by 10 to 15°C. The measures taken include flow adjustments, redesign and modification of many consumer substations. In the separate Chapter A Chapter A.9 we describe this revamp of the consumer substations.

A.2.4 Base case: Nykvarn

In Sweden the price of ground-mounted flat plate collector arrays has decreased substantially during the last decade. That history was summarised in Table A.1. In this report we use the CSHPDS of Nykvarn I as a reference. It is connected to a DH system, which is comparable to that at Falkenberg. The design and size of the CSHPDS itself is similar in the two plants. Furthermore, the operating conditions were very much the same at the two sites. The DH return temperature was a few degree Celsius lower of Nykvarn I and the solar radiation was slightly higher at Falkenberg. However, there is one notable difference. The heat distribution pipe between the storage and the collector array is 720 meter at Falkenberg and only 60 meter of Nykvarn I. However, there is a 1000 meter heat distribution pipe at Nykvarn, part of the cost of which should be added to the price of the CSHPDS. When it was decided to build the CSHPDS at Nykvarn no permanent DH plant existed. Thus, one choose a site with space for a collector array and built the plant and the CSHPDS simultaneously. The 1000 meter heat distribution pipe connects the new plant to the old network.

A.3 The solar heating plant CSHPDS

The central solar heating plant with diurnal storage (CSHPDS) at Falkenberg shall supply heat to the DH network and thereby replace burning of fuels in the DH plant. During fine weather in summer the plant shall supply a dominating part of the total heat delivered to the DH network, whereas the solar part of the yearly heat delivered will at best be 10 per cent. Furthermore, it shall be possible to use the water-tank of the CSHPDS for short term storage of heat from the wood-chip boilers.

The design of the plant at Falkenberg is based on that of the plant at Nykvarn. The goals were to reduce the investment cost significantly without sacrificing on the thermal performance or durability. The main approach was to simplify wherever possible.

Figure A.1 shows a schematic of the collector loop, the storage, and the DH plant. The nearest ground suitable for a collector array was found half a kilometre away from the old DH plant. Thus, a 720 m heat ground buried district heating pipe connects the collector array to the plant.
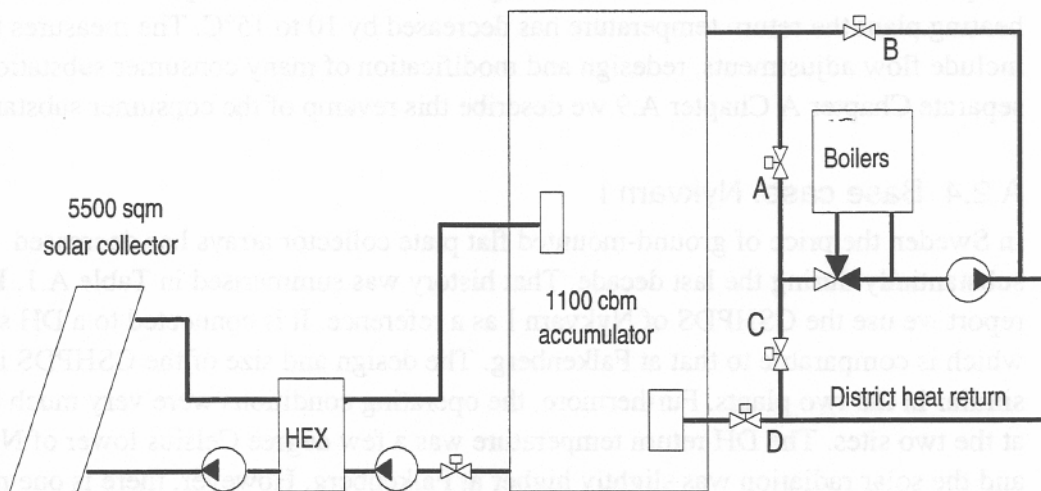
Figure A.1. The solar heating plant and the DH plant at Falkenberg. The collector array is situated half a kilometre away from the plant.

A.3.1 The Solar Collector Loop

The solar collector loop consists of a 5500 m^2 collector array, an 720 m district heating pipe, a circulation pump, and a flat plate heat exchanger. The working fluid used is a 50 per cent mixture of water and propylene glycol.

Figure A.2. shows the collector array placed on a non-fenced field between farmland and a major road. The array comprises a total glazed area of 5500 m^2. The collectors are facing 5° East of South and they are tilted 38° from horizontal. The groundwork for the array is simple. The top-soil is removed, the ground is somewhat levelled off, and the DH pipes are burrowed 0.2 m under the surface. Then, two concrete slabs per collector module are placed directly on top of the ground. The collector modules are then mounted on the concrete slabs. Finally, they are connected by flexible hoses.

Figure A.3 show the lay-out of the array. It is composed of 440 modules of 12.5 m2. These are arranged into two parallel blocks each of which comprise twenty-two parallel
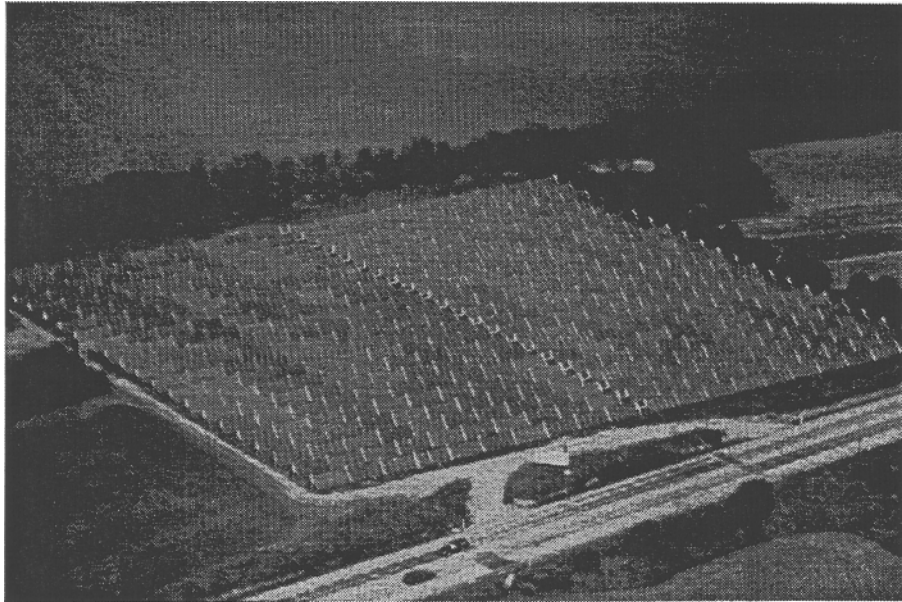
Figure A.2. The solar collector array at Falkenberg.

rows. These in turn comprise ten collector modules, which are connected in series with flexible hoses and compression fittings. At the inlet of each row there is a balancing, and a pressure relief valve. At the outlet there is shut-off valve. The collector flow is equivalent to 0.0046 kg/m^2.s of water.
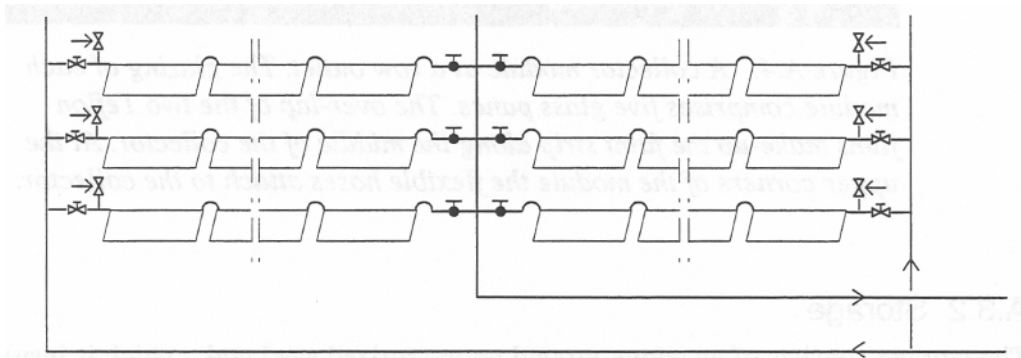
Figure A.3. The layout of the solar collector array.

A.3.1.1 Collector module

The collector (TeknoTerm AB, model HT) comprises one pane of low iron glass, one layer of Teflon film, and the selective SunStrip absorber. The frame of the collector box is made of extruded aluminium profiles and the back-side is made of a corrugated aluminium plate. The absorber is approximately six by two meters and comprises six meter absorber strips in parallel between two headers. This configuration limits the total flow resistance of the collector module. Moreover, the strips make up the dominating contribution to that resistance, securing an uniform flow distribution within the module and allowing both the inlet and the outlet to be located at the top of the module. Thus, these modules are appropriate to connect in series.

    TeknoTerm have successively developed their technique to mount the Teflon film convection barriers. Prior to Falkenberg they used double film with little pre-stress.

Typically the film partly sticks to the outer cover and also to the absorber resulting in a performance penalty. Furthermore, the second film can hardly be motivated by its contribution to the performance.

In the Falkenberg version of the HT collector they use one 50 micron Teflon film. Two 6 by 1.2 meter films are fixed in extruded aluminium profiles, which in turn are mounted to the headers. The films are further supported by the glass-support. Thus, the films are not supported along their longer edges. The films are pre-stressed so that they supposedly do not sag when heated.
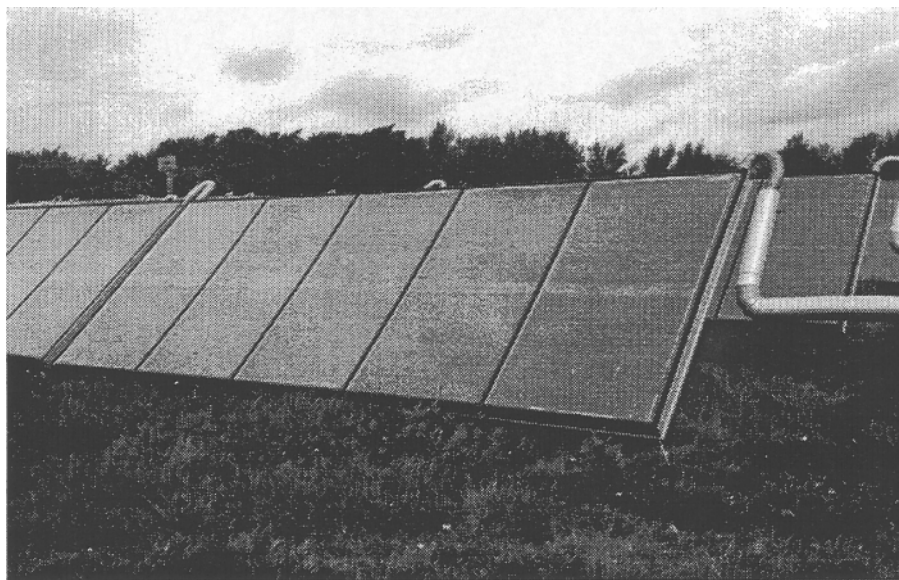
Figure A.4. A collector module at a row outlet. The glazing of each module comprises five glass panes. The over-lap of the two Teflon films make-up the faint strip along the middle of the collector. At the upper corners of the module the flexible hoses attach to the collector.

A.3.2 Storage

The storage consists of an above-ground unpressurized steel tank, which is insulated with 600 mm of mineral wool. The tank is drawn to scale in Figure A.5. The tank is 26 m tall and contains 1100 m^3 of water. The DH network and the tank have a common water volume and the tank serves as an expansion vessel for the network. Because of architectural considerations the tank is taller than required by technical reasons.

The tank is unpreassurized, i.e. above the water surface there is atmospheric pressure. However, to avoid an inflow of oxygen and as a result corrosion, an additional pressure of a few hundred Pa is maintained by means of a water-lock and a steam boiler. To secure the structural integrity of the tank the water-lock opens at a pressure of 1 kPa above the atmospheric pressure and at 0.4 kPa below. This is standard DH technique.

The tank and its inlets are designed to support temperature stratification. At Nykvarn the tank has two inlets at the collector side and a three-way valve to switch between the two. Thus, depending on the supply temperature the water is inserted either at a high or a low level of the tank. The configuration at Falkenberg is less complex as shown in Figure A.5. The inlets are connected to short vertical tubes inside the tank, the purpose of which are to suppress mixing of water of different temperatures. The DH return temperature

varies over the day, which motivates such a device also at the inlet on the DH side. At Nykvarn the highest DH return temperatures appear at late night. Thus, the temperature at the bottom of the tank typically increases a few degree Celsius before the collection of solar energy starts.

A.3.3 Control

Figure A.6 shows the location and the symbols of the sensors and the controlled devices. The control hardware is all located the DH plant. The control system of the CSHPDS is greatly simplified compared to that of the Nykvarn plant. There is only one inlet to the storage from the collector side and one outlet to the DH side, thus saving two three-way valves an their controls. Furthermore, there is no separate pump for pre-heat circulation in the collector loop. Lastly, the four valves A, B, C, and D on the DH side are all manually operated.

The CSHPDS may be operated in a number of different modes. The storage splits the plant in two sides, the modes of which are coupled only by the temperatures in the tank. The operating modes of the solar collector side are listed in Table A.2 and those of the DH side in Table A.3.

Figure A.5. The 1100 m³ heat storage.

A.3.3.1 Control of the solar heat collection

The collector loop is pre-heated before the solar heat is charged into the storage. The circulation in the collector loop starts when the temperature GT1 in a separate "reference collector" reaches a certain temperature, pre-set to 40°C. In this way, the fluid of the collector loop ninety per cent of which is in the DH pipes is heated. When the fluid temperature GT2 at the inlet of the heat exchanger exceeds the temperature at the bottom of the tank by a small difference, pre-set to 4°C , the circulation in the charging loop starts and heat is injected into the storage.

Figure A.6. Sensors and controlled devices used to control system operation.

Table A.2. Operating modes of the collector and the charging loops.

	Mode	Start condition	Stop condition	P-sun	P-charge
1	Pre-heating of the collector loop	GT1 > 40°C	GT1 < 40°C	ON	OFF
2	Collecting solar energy	GT2 > GT3 + 4°C	GT2 < GT3	ON	ON
3	Emergency stop and alert signal	GT4 > 95°C		OFF	OFF
4	Dumping of heat	Not implemented			

A.3.3.2 Control of the heat supply to the DH network

The CSHPDS serves as a pre-heat system to the conventional DH plant. The CSHPDS does neither affect the control of the DH flow nor of the DH supply temperature. However, when the temperature at the top of the tank is higher than the required supply temperature the water from the top of tank is directly supplied to the net.

Table A.3. Operating modes of the load side

	Mode	Valves			
		A	B	C	D
5	Delivering of solar heat (Summer)	Open	Closed	Closed	Open
6	Charging of the storage	Closed	Open	Open	Open
7	Storage disconnected (Winter)	Open	Closed	Open	Closed

There is an operation mode (Table A.3 mode 6) to store heat from the boilers. The valve B is open and part of the supply flow is diverted to the "outlet" at the top of the tank. Finally, the tank may be shut-off from the DH system by closing valve D. During the winter net losses would occur if the tank is heated by the DH return water.

A.4 Operation and maintenance

The CSHPDS at Falkenberg was built during the summer 1989 and it was put into operation in the autumn. From January 1990 through December 1992, which is the period covered by this report the plant was monitored and operated without any major problems. The plant is still operating and no additional problems have been reported at the time of writing this report, spring 1994.

A.4.1 Malfunctions

However, a number of problems have been encountered. Leakage at the fittings between the flexible hoses and the collector modules has occurred. The Teflon film has broken in some collector modules. At a couple of occasions we observed very low flow rates and boiling in a few collector rows. Finally, the water-lock and the steam boiler do not effectively prevent ambient air from entering into the top of the tank.

A.4.1.1 Leakage in the collector array

There have been frequent small leakage at the fittings between the flexible hoses and the collectors. At one occasion there was a larger leakage at the end of one row. Fluid entered into the insulation of the DH pipe and its alarm system indicated moisture. The fittings in the collector arrays have been checked and tightened several times. A cubic meter of working fluid or more has been lost every year.

The same type of flexible hoses and fittings join the same type of collector modules at Nykvarn. However, neither in the old part nor in the new part of the collector array at Nykvarn there has been any leakage worth to mention. The reason for this difference between the two arrays is not yet explained.

A.4.1.2 The Teflon film convection barrier

Teflon film is a delicate material to use as convection barrier in solar collectors. The Falkenberg collector features a convection barrier made out of a single 50 micron Teflon film mounted in special profiles along the ends of the absorber. The film is further supported by the frame holding the outer cover.

The Teflon film exhibits malfunctions in many collector modules. However, it is difficult to characterise the failures by inspection from outside and consequently our description is rather vague. In roughly two per cent of the collector modules the film has broken at one of the upper corners along the profile. The corner of the film is hanging and the rip develops very slowly down along the profile. Figure A.7 shows a sample of such a failure. TeknoTerm have repaired these convection barriers on site. In another maybe ten per cent of the modules the upper edge of the film is sagging although we cannot see any rip.

From time to time the Teflon film adheres to the outer cover in a significant portion of the collectors. Without doubt, some moisture between the film and the glass promote this adhesion. Visually, the Teflon film convection barriers are in a better condition now after few years in operation than when they were new. One reason is that the Teflon film shrinks when cycled in temperature.
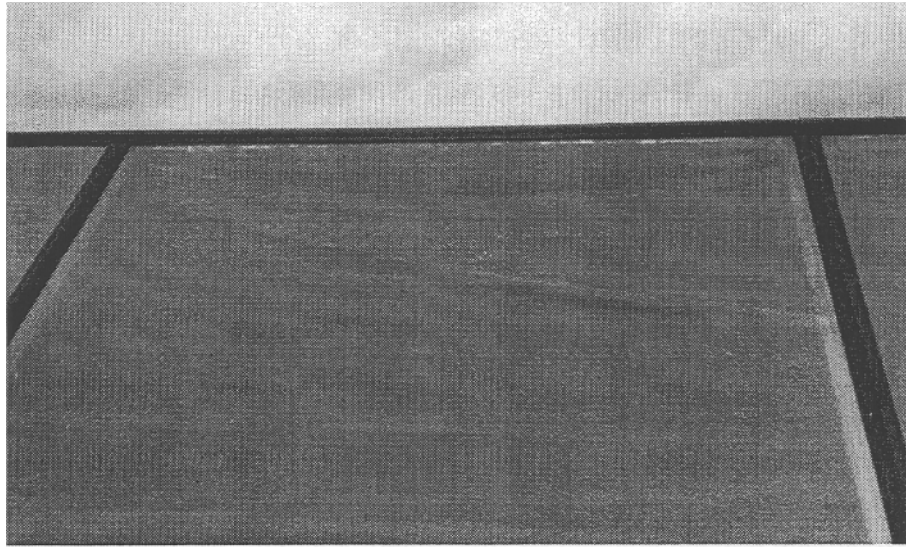
Figure A.7. A collector with the upper edge of the Teflon film sagging.

A.4.1.3 The flow distribution in the collector array

The collector array consists of two groups in parallel, each of which comprises 22 rows in parallel. The dominant pressure drop occurs over the rows, which comprises ten collector modules in series. At the inlet of each row, there is a balancing valve with outlets for pressure difference measurements. The flow was balanced after installation of the array and at a couple of occasions we have checked the flow distribution.

August 23, 1990, we carefully measured the surface temperature of the pipe at the outlet of each row. The array inlet temperature was 66°C and the outlet temperature was 89°C, approximately. The inspection took one and a half hour and we typically recorded values in the range of 81 to 84°C. However, in the far part of the array we found the temperatures 99, 101, 107, and 114°C, at four row outlets. It was obvious from the sound that boiling occurred in a couple of these rows. On request TeknoTerm balanced the flows in the array.

October 23, 1991, we made a second check. This time we used an IR-thermometer and measured glass temperatures near the row inlets and outlets. The solar irradiance was approximately 700 W/m^2. Another four rows at the far end of the array exhibited very high glass temperatures, indicating low flow rates. The sound of the flow at the row outlets confirmed that the flow rates were low. We have not found the reason to these low flow rates. Furthermore, the array at Nykvarn, which is very similar does not exhibit these problems.

A.4.1.4 Glass breakage

Only a few panes of glass have been damaged in the Falkenberg collector array. The situation is different at Nykvarn and Lyckebo, where dozens of panes are broken each year by stone-throwing.

A.4.1.5 Oxygen entrainment in the storage tank

The storage tank is unpressurized and it is equipped with a water-lock and a steam boiler to prevent entrainment of ambient air. This is standard DH technique in Sweden. Due to thermal expansion of the water its surface ascents and descends with the amount of stored heat. Steam is injected above the surface to keep the excess-pressure within a narrow interval, required by the structural integrity of the tank. Ambient air should never pass through the water-lock. Condensation should maintain the water level in the lock.

However, these devices do not work properly in the Falkenberg tank. Corrosion occurs in the system due to an inflow of oxygen. There is no easy mean to inspect the water levels in the lock. However, in August 1992 we disassembled and inspected the water-lock and found that it contained too little water to close properly. Furthermore, its internal walls were dry and it seemed unlikely that condensation under the circumstances would refill the lock. Neither does the steam boiler work well. Frequently, it has been shut-off automatically because of insufficient water supply.

The Nykvarn plant includes a similar system, which exhibits the same type of problems. Thus, a standard solution that works in DH systems seems not to work reliably in solar heating plants. The steam boiler water-lock system encounters conditions in solar heating plants, which differ from those in standard DH plants. In the latter the water surface is maintained at a constant high temperature (above 90°C) whereas in solar heating plants it regularly decreases below 70°C. Thus, the condensation rate is higher. However, we currently do not fully understand the reasons for the failure in these two solar heating plants.

A.4.2 Maintenance

Grass and shrub grow between the collector rows (Figure A.8). Until now, only the shrub has been cut and thus the vegetation causes minor shadowing of the collectors especially at the end of the season.
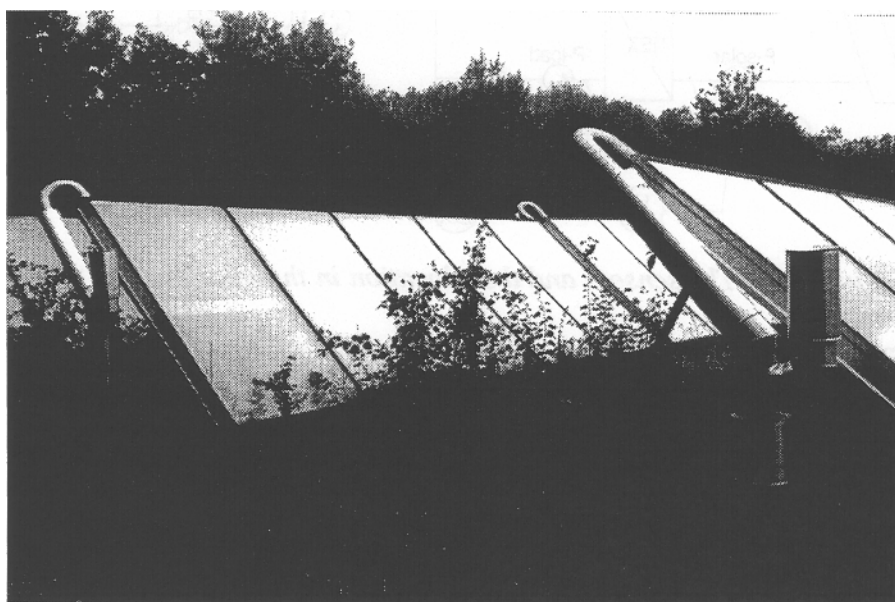
Figure A.8. Grass and shrub are growing fast between the collectors

A.5 Evaluation Program

The purpose of the evaluation program is to develop a thorough understanding of how the CSHPDS works and thus contribute to a knowledge-base for improved future designs. The approach is to monitor the plant carefully, describe the performance in detail and then do simulation studies. However, this report does not include results from simulation studies.

Furthermore, this evaluation supplies the data needed to determine whether the thermal performance guaranteed by TeknoTerm is fulfilled. We describe our system of designations in Section A.5.2.

A.5.1 Monitoring Program

The plant was monitored from January 1990 through November 1992. Values from 57 sensors have been sampled continuously with 87 measured or derived quantities recorded every hour. Two minute values have been recorded for some thirty quantities during certain periods.
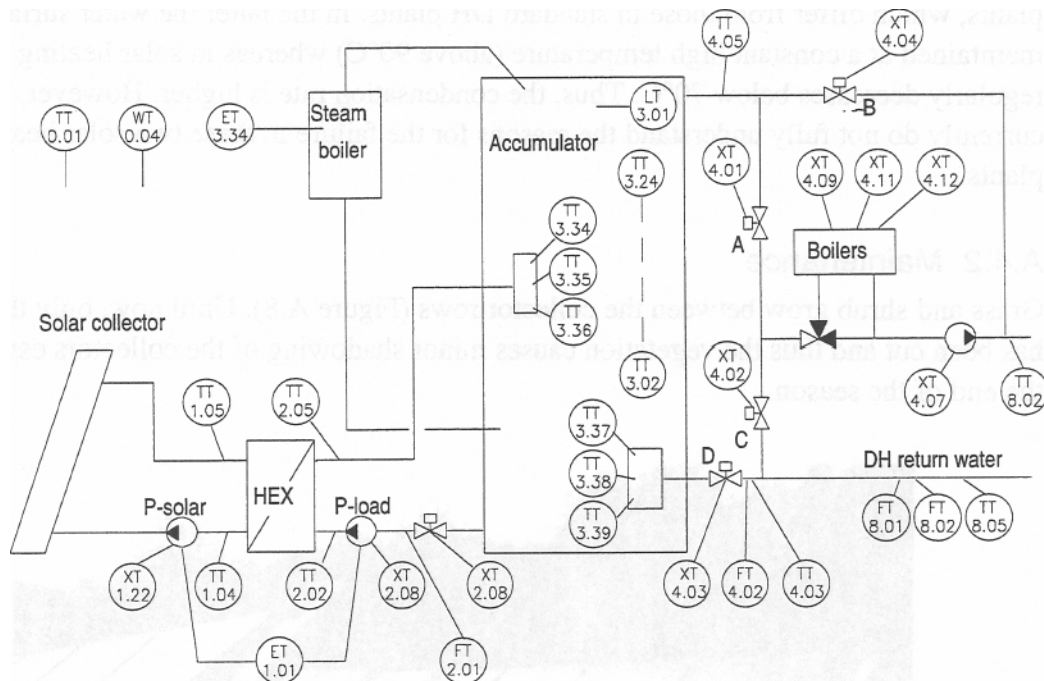
Figure A.9. The sensors and their location in the solar heating plant.

Flow rates and temperatures are measured separately and the heat flow rates are calculated by the data acquisition computer. Table A.4 lists the thermal energy quantities recorded in the experiment. Temperatures are measured at some thirty levels in the storage.

The data acquisition system used has exhibit a very high availability. From the start in January 15 1990 to the end of November 1992 the system was down for only 30 days. Measured data for 10 days were lost in December 1991 and 8 days in September 1992. Data for very few days were lost in the summers.

Table A.4.   Four thermal energy quantities were recorded.

Symbol	
Q23	The heat flow from the charging loop to the storage
Q35	The heat flow from the storage to the delivery loop
Q45	The heat flow from the boilers to the delivery loop
Q56	The heat flow from the delivery loop to the DH network.
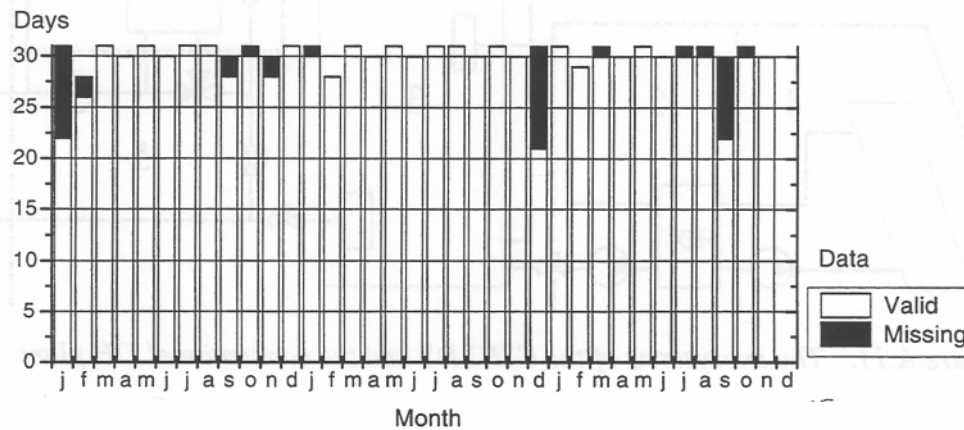
Figure A.10. The availability of the data acquisition system.

The sensors were calibrated before and at least once during the monitoring period. The uncertainty of absolute temperature measurements is estimated to be ±0.1°C. The flow rates before and after the storage tank are measured with an uncertainty of ±0.5%. The uncertainty of the heat flow from the solar collector field is ±1.0% while the uncertainty of the heat flow from the storage tank to the district heating system is ±2% on a typical summer day ($\Delta t = 5°C$ and the flow rate = 80 m^3/h). The uncertainty of the solar irradiation is less then ±3% momentarily but the uncertainties of the calculated hourly values are lower.

A.5.2 Designations of sensors and performance factors

Our systems of designations of sensors and performance factors (see Figure A.12 and Figure A.13) are based on a division of the entire system into subsystems as shown in Figure A.11 and listed in Table A.5.

The energy weighted average temperature, *TeMN,* which is used to indicate the quality of the heat, *QMN,* transferred from source subsystem *M* to the target subsystem *N* is calculated according to

$$TeMN = \frac{1}{2} \cdot \frac{\sum QMN \cdot (TMN + TNM)}{\sum QMN}$$

where *e* indicates energy weighted, *TMN* is the temperature at the inlet of subsystem *N* of the fluid coming from subsystem *M*, and *TNM* is the temperature at the outlet of subsystem *N* of the fluid leaving for subsystem *M*. A few examples will clarify the use of these notations:

Q12 The heat delivered from the solar collector loop 1 to the charging loop 2.

Te 12 The energy weighted temperature at which the heat, Q12, is delivered from the solar collector loop 1 to the charging loop 2.

Ns05 The efficiency of heat transfer from ambient 0 to the delivery loop (5 (Q35/Q01).
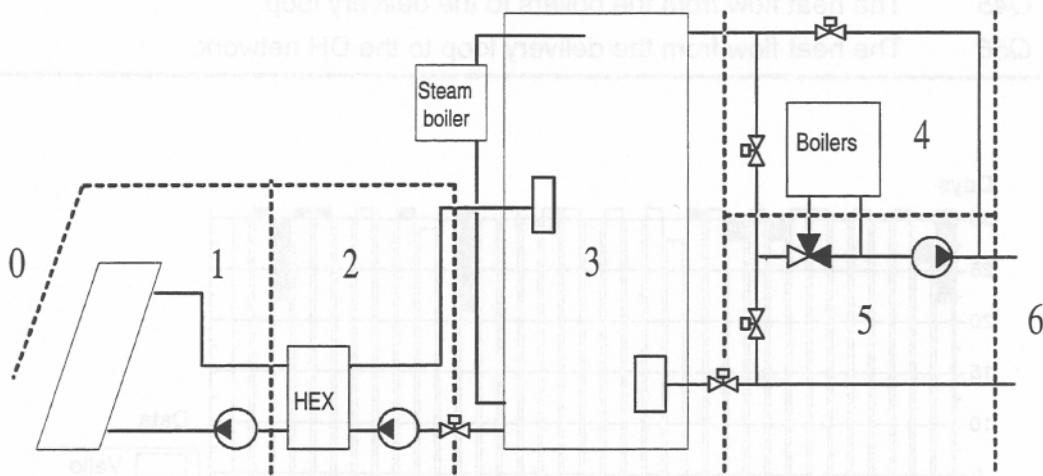
Figure A.11. The subsystems of the CSHPDS and the conventional DH plant.

Table A.5.   Subsystem designations.

Code	Subsystem	Comments
0	The surrounding of the plant	Including the electrical network
1	The solar collector loop	
2	The charging loop	
3	The heat storage	
4	The conventional boilers	
5	The delivery loop	
6	The DH network	
S	CSHPDS,	The union of the subsystems 1, 2, and 3

A T M . N

Measured **Quantity**
Output function
Source subsystem
Consecutive **number**
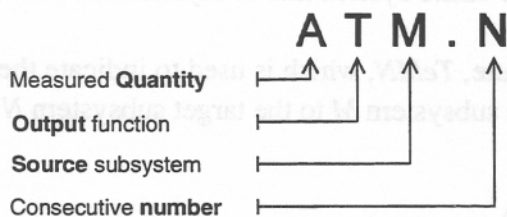
Figure A.12. The system for designating the sensors. Output function "T" stands for transmit, which applies to all recorded quantities.

A a M b N c

Type of **Quantity**

   attribute of **quantity**

Source subsystem

   attribute of **source**

Target subsystem

   attribute of **target**
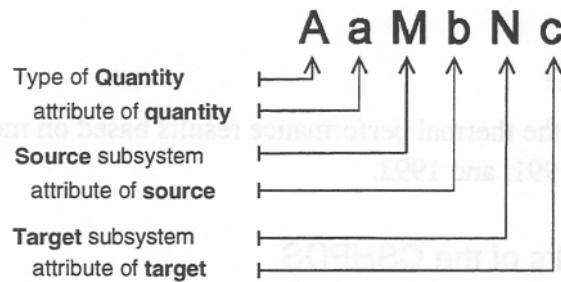
Figure A.13. The system for designating thermal performance factors.

Table A.6. Letter designations for physical quantities. Capital letter

Code	Quantity	Comments
E	Electrical energy	Electricity meter, 1%
F	Volume flow	Krohne or Clorius inductive flow meter
N	Ratio	E.g. efficiency
Q	Thermal energy	
T	Temperature	Pentronic PT100 1/10 DIN
W	Solar irradiance	Kipp & Zonen, CM 11
X	ON/OFF, Elapse time, etc.	

Table A.7. Lower case letter

Code	Quantity	Comments
d	Difference	
e	Energy weighted average value	
o	During operation	
s	Solar	

A.6 Measured Performance

This section includes a description of the thermal performance results based on measured hourly data for the three years 1990, 1991, and 1992.

A.6.1 Annual and monthly results of the CSHPDS

The average thermal performance of the CSHPDS at Falkenberg is summarised in Figure A.14.
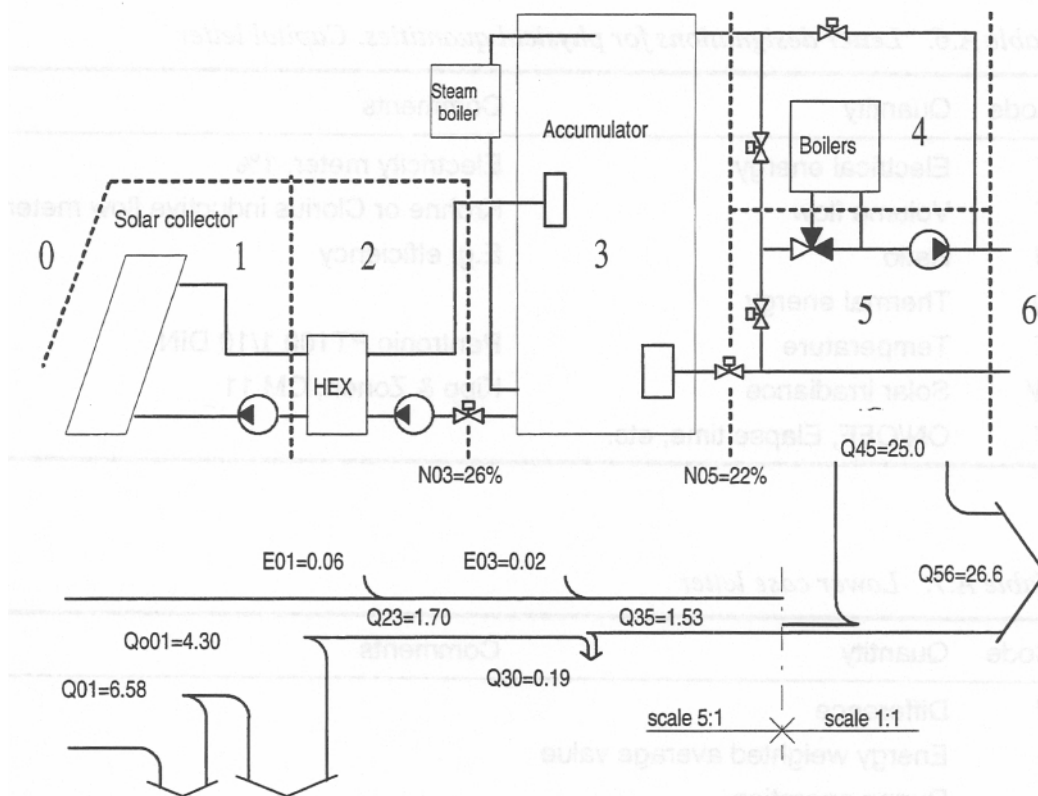
Figure A.14. Energy flow diagram for the CSHPDS at Falkenberg during the three year period 1990 through 1992. The energy quantities are yearly averages [GWh] (1 GWh = 3.6 TJ).

During the three years 1990, 1991, and 1992 the CSHPDS delivered a yearly average of $Q35 = 5.5$ TJ ($\pm 2\%$). Subtracting the electrical energy used to operate the CSHPDS, $EOS = 0.3$ TJ results in the net solar energy delivered to the DH network, $Qs3 = 5.2$ TJ. During this period the yearly DH load was $Q56 = 95.8$ TJ ($\pm 3\%$) and thus the solar fraction of this load, $N9 = 5.5\%$. The yearly average of solar incident upon the collector array was $Q01 = 23.7$ TJ and consequently the yearly CSHPDS system efficiency was $Ns05 = 22\%$. This result is good although it does not fulfil the design goals.

    In Figure A.14 it is worthy to note that more than a third of the solar insolation ($Q01$ - $Qo01 = 8.2$ TJ) occurred while the plant did not collect energy. The insolation is too low to compensate for the losses. Thus, the collector loop efficiency, $N03 = 26\%$, based on the total insolation is much lower than the efficiency during collection, $No03 = 40\%$. The solar heat was delivered to the heat exchanger at an energy weighted average temperature of $Te12 = 69°C$.

Table A.8 presents a large set of thermal performance factors of the Falkenberg CSHPDS for the years 1990 through 1992. All the energy quantities refer to unit area of collector. Missing data for 30 days (see Figure A.10) have been substituted by the averages for the month in question. Data from November through February are excluded from the calculation of the temperatures $To0$, $Te\,12$ and $Te23$.

Table A.8.   *Thermal performance factors for the three years 1990-1992.*

Thermal performance factor	Symbol	1990	1991	1992	Unit
Total solar incident in the collector plane	Q01	4428	4176	4320	MJ/m²
Average ambient temperature	T0	9.2	8.2	8.9	°C
Total solar incident while collecting	Qo01	2866	2657	2927	MJ/m²
Average ambient temp. while collecting	To0	14.4	15.2	16.5	°C
Solar energy collected	Q23	1066	1073	1192	MJ/m²
The collector loop excess temperature	Tdo01	53.1	48.6	49.7	°C
Temperature of solar energy collected	Te12	71.2	66.5	68.6	°C
Charging loop operating hours	K2	1190	1120	1120	h
Solar collector loop efficiency	N03	24	26	28	%
Solar collector loop on efficiency	No03	37	40	41	%
Temperature of solar energy to storage	Te23	66.1	61.3	63.1	°C
Total heat losses from the storage	Q30	151	97	137	MJ/m²
Total useful energy from the storage	Q35	922	994	1087	MJ/m²
Temp. of the useful energy from storage	Te35	61.7	57.2	58.7	°C
Solar energy utilised	Qs35	882	936	1033	MJ/m²
Total CSHPDS operating energy	E0S	40	54	54	MJ/m²
CSHPDS conversion efficiency	Ns05	20	22	24	%
Total auxiliary energy	Q45	82	94	94	GJ/m²
Total energy delivered	Q56	87	99	100	GJ/m²
Temperature of energy delivered	Te56	68.7	67.9	66.8	°C
Solar fraction of energy delivered	N9	5.6	5.2	5.7	%

Figure A.15 shows a set of monthly performance factors for the collector and the charging loop for the year 1992. December data are excluded. During 1992, both March and April exhibit remarkable low values for the solar incident on the collector $Q01$ whereas June and September show high values. The solar energy collection is concentrated to the period between the vernal and the autumnal equinoxes. The solar energy collected during the winter is negligible. The collector loop working temperature Tol, i.e. the average between the inlet and outlet while collecting, is around 60°C in spring and autumn. During summer it is higher around 70°C. The temperature drop over the heat exchanger is around 5°C as seen from the difference Tol -$To23$. The monthly collector loop efficiency $N03 = Q23/Q01$ is in the range of 25% - 35%, whereas the efficiency while collecting is around No03 ≈ 40%. In June the plant collected energy during slightly more than K2 = 8 hour per day, which in Sweden is a high value for this type of plant.
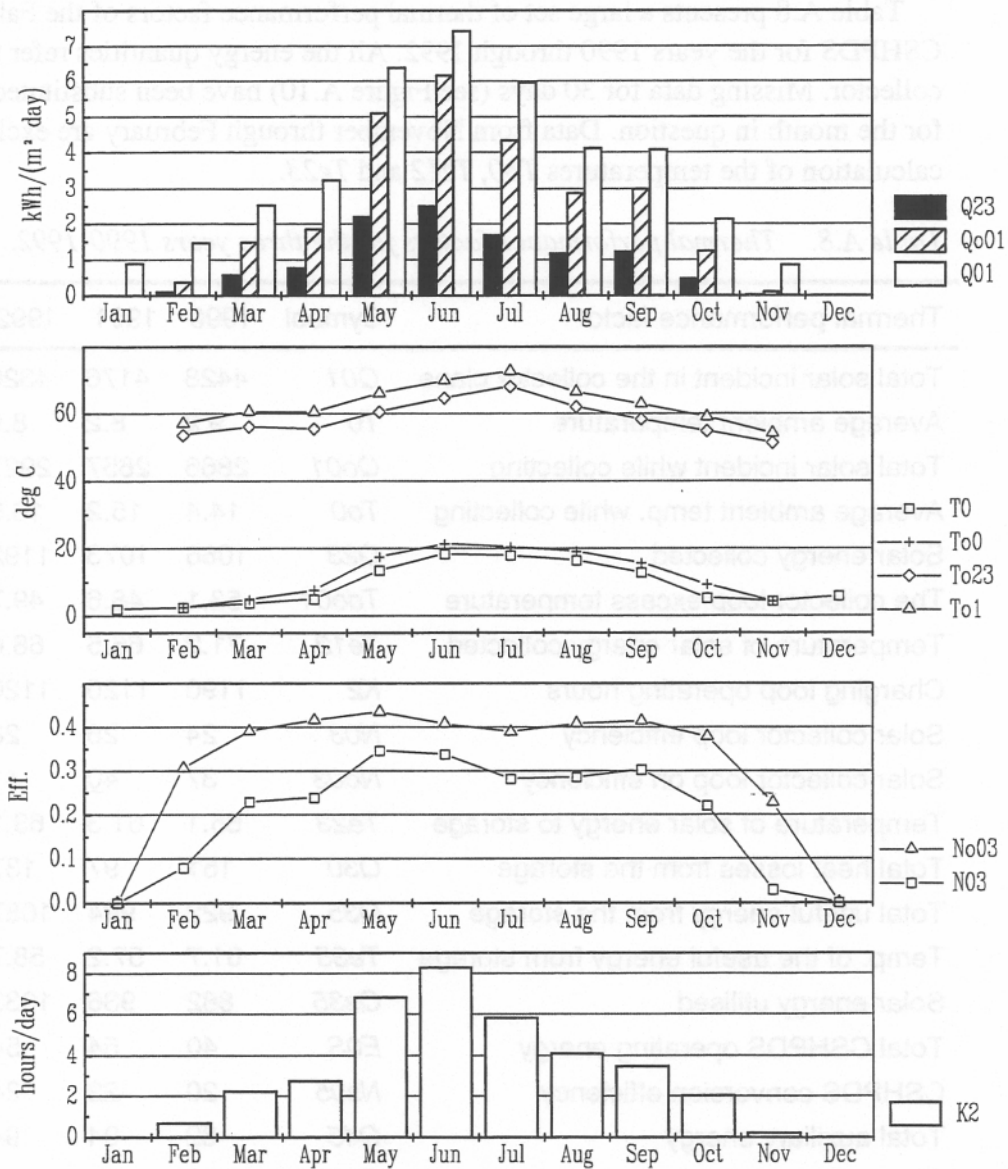
Figure A.15. Overview of the operation of the solar collector and charging loops during 1992. All values presented are monthly averages of daily values.
Diagram 1. Average energy supply rates for the collector TeknoTerm HT in the Falkenberg CSHPDS. The quantities are the total solar incident in the plane of the collector, Q01, while collecting, Qo01, and solar energy collected, Q23. (1 kWh = 3.6 MJ)
Diagram 2 shows the outdoor temperature, TO, as well as three temperatures during operation, the outdoor temperature, To0, the operating temperature of the collector field, Tol, and the operating temperature of the load circuit, To23:
Diagram 3 shows the efficiency of the solar collector system, NO3, and the efficiency during operation, No03.
Diagram 4 shows the daily operating times, K2, of the charging loop.

A.6.2 Daily Input / Output diagrams

Figure A.16 presents daily Input / Output diagrams for the temperature interval
45°C < Tde01 < 60°C. Regression lines have been determined for four classes of daily
sums of solar energy collected, *023,* vs. total solar incident in the collector plane, *Q01,*
(Table A.9). Points where *Q01* < 7.2 MJ/m^2 and a few points with extremely low values
for *Q23* are excluded (Figure A.16).
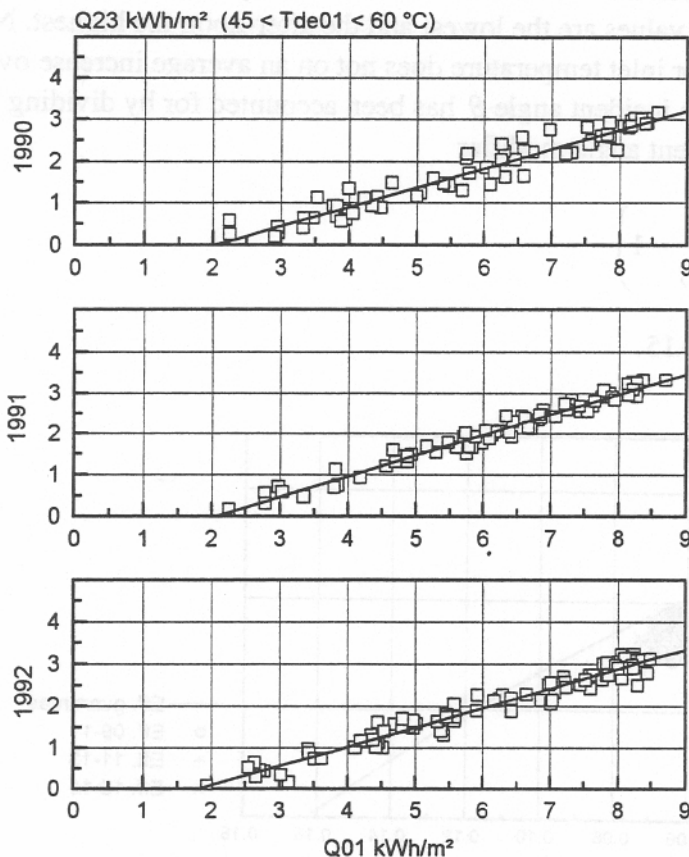
Figure A.16.
Daily Input/Output diagram
for the CSHPDS at Falken-
berg. Type of collector:
TeknoTerm, HT Time period:
1991, 1992, and 1992. Range
of temperature difference:
45 < Tde01 < 60°C. (1 kWh
= 3.6 MJ)

Table A.9. Linear regression: $Q23 = k \cdot 001 + 1$ *for the daily*
Input/Output diagrams.

Year		Class		k	l	r^2	N
1990		Tde01	< 45	0.48	-0.797	0.75	4
1991		Tde01	< 45	0.42	-0.751	0.96	34
1992		Tde01	< 45	0.42	-0.654	0.96	20
1990	45 <	Tde01	< 60	0.46	-0.929	0.96	65
1991	45 <	Tde01	< 60	0.50	-1.03	0.98	79
1992	45 <	Tde01	< 60	0.46	-0.823	0.98	103

A.6.3 The collector loop efficiency

Figure A.17 presents a collector loop efficiency diagram. It is based on hourly data from selected days with clear sky in the period April through September, 1991. During these selected days solar heat is collected continuously at least from 9.00 until 15.00 hour. The efficiency points have been divided into three 2-hour classes, morning 09-11, noon 11-13, and after-noon 13-15. Swedish standard time, i.e. GMT + 1 hour is used. The collector azimuth is 5° East of South and the array is located at the longitude -12.5°.

　　No corrections have been made to account for the heat capacity of the collector, which explain why the morning values are the lowest and the after-noon the highest. Note, however, that the collector inlet temperature does not on an average increase over the day.

　　The dependence on the incident angle O has been accounted for by dividing the solar incident $Q01$ by the incident angle modifier

$$K_{\alpha\tau} = 1 - b_0 \cdot \left(\frac{1}{\cos(\theta)} - 1 \right)$$

where we assumed $b_0 = 0.15$.
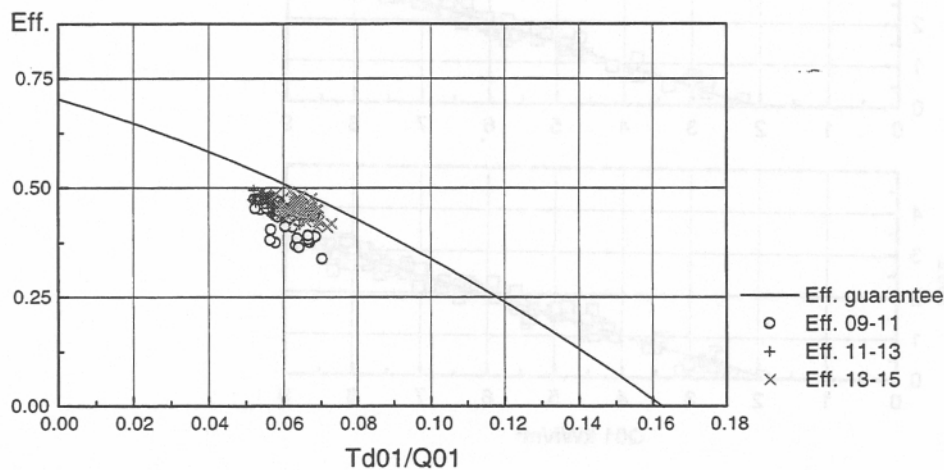
Figure A.17. Collector loop efficiency diagram at Falkenberg, 1991. Type of collector: TeknoTerm, HT. The solid curve represents the 'fine weather" efficiency based on the manufacturer's data.

Figure A.18 presents blow-ups of the collector loop efficiency diagram for the three years 1990, 1991, and 1992. A linear collector model has been fitted to the data of the three classes, morning, noon, and after-noon, respectively. The fitted models are included in the diagrams. The collector loop inlet temperature is dominated by the DH return temperature, which is fairly constant. Thus, there is a limited range of values, which makes it difficult to identify the efficiency parameter values.

　　The density of the points indicates the typical working conditions of the collector loop.
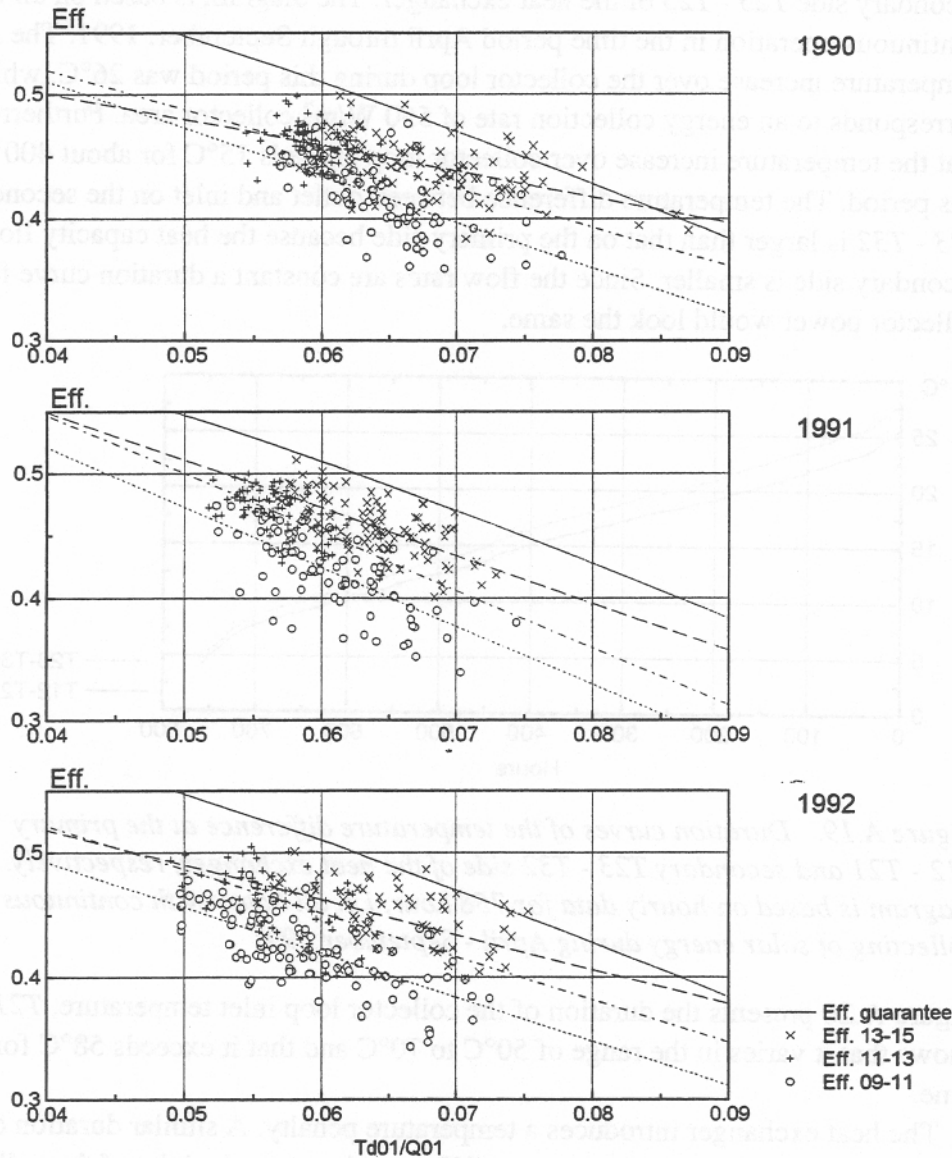
Figure A.18. Collector loop efficiency diagram at Falkenberg. Period: 1990, 1991, and 1992. Type of collector: TeknoTerm, HT. The solid curve represents the 'fine weather" efficiency based on the manufacturer's data. The diagrams are based on data from selected days with clear sky. Linear regression has been used for the three classes of data. The dotted line represents morning values, the dash dotted line represents noon and the dashed lines represent the afternoon values, respectively.

A.6.4 Temperatures in the collector loop

In this section the temperatures in the collector loop are presented based on hourly data for all hours with continuous collecting of solar energy during April - September 1991. The fluid flow rates in the collector and the charging loops are nearly constant during operation. The total water flow rate in the charging loop is 25 kg/s, which referred to collector area is 0.0045 kg/s.m^2. The heat capacity flow rate in the collector loop is 10% higher, approximately.

Figure A.19 shows the duration of the temperature difference between the inlet and the outlet at the primary side *T12 - T21* and the difference between outlet and inlet at the

secondary side *T23 - T23* of the heat exchanger. The diagram is based on all hours with continuous operation in the time period April through September, 1991. The largest hourly temperature increase over the collector loop during this period was 26°C, which corresponds to an energy collection rate of 550 W/m^2 collector area. Furthermore, we see that the temperature increase over collector loop exceeds 15°C for about 400 hours during this period. The temperature difference between outlet and inlet on the secondary side *T23 - T32* is larger than that on the primary side because the heat capacity flow rate on the secondary side is smaller. Since the flow rates are constant a duration curve for the collector power would look the same.
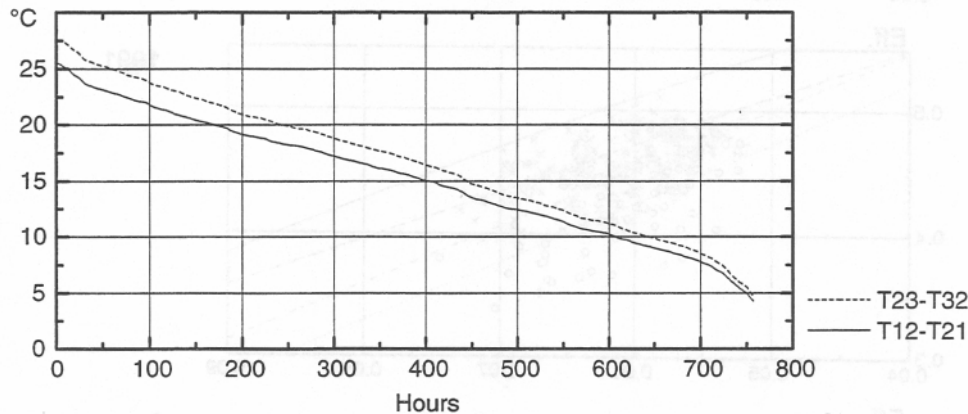
Figure A.19. Duration curves of the temperature difference at the primary T12 - T21 and secondary T23 - T32 side of the heat exchanger, respectively. The diagram is based on hourly data for 758 hour, i.e. all hours with continuous collecting of solar energy during April - September 1991

Figure A.20 presents the duration of the collector loop inlet temperature, *T21*. The diagram shows that it varies in the range of 50°C to 70°C and that it exceeds 58°C for half of the time.

The heat exchanger introduces a temperature penalty. A similar duration diagram over *T21 - T32* shows that the temperature difference between the inlet of the collector loop *T21* and the outlet of the storage *T32* varies in the range of 2°C to 9°C and exceeds 5°C for 450 hours.

Lastly, the difference between the collector loop average temperature and ambient *Tdo01* is on the average 51°C and at the most 67°C.
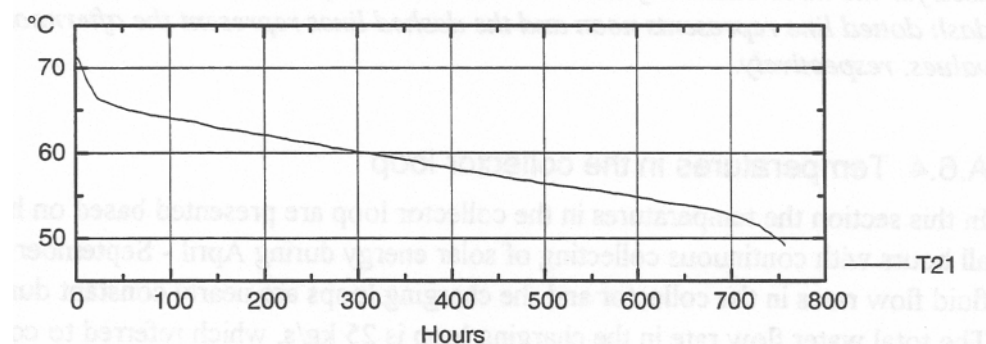
Figure A.20. Duration curve of the inlet temperature of the solar collector loop, T21, during 1991. The diagram is based on hourly data for all hours with continuous collecting of solar energy during April - October 1991.

A.6.5 Temperature stratification in the storage

The behaviour of temperatures in the tank while charging and discharging, respectively, is presented in Figure A.21 and Figure A.22. The diagrams cover the time period from 8 a.m. June 12, 1990 through 4 a.m. the following morning and they display temperature profiles for every second hour. A detailed drawing of the tank is presented in Figure A.5 and the positions of the inlets and outlets are indicated in the diagrams. Note that the two inlets are equipped with 2.5 meter vertical tubes.
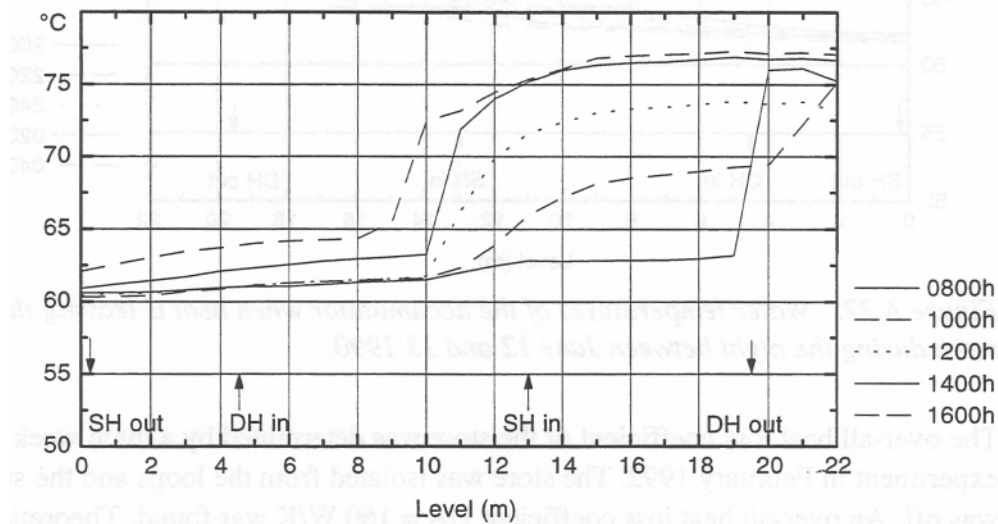
Figure A.21. Water temperatures in the accumulator June 12 1990. 'DH in' and 'SH in' marks the positions of the inlets of the district heating and solar heating systems respectively. 'DH out' and 'SH out' marks the positions of the outlets.

The flow rate in the charging loop was 0.026 m^3/s while collecting and that in the delivery loop was constantly 0.022 m^3/s through-out that day. Thus, while collecting there is a net downward movement of the water between the charging loop inlet and the delivery loop outlet of one meter in four hours. The two vertical inlet tubes each have one temperature sensor at the top, one in the middle, and one at bottom (see Figure A.9). Data from these sensors make it possible to judge the flow and mixing in the vertical tubes.

   In the first morning the storage is completely discharged, i.e. below the outlet to the delivery loop the temperature is 62°C, which is close to the temperature of the DH return. At 10 pm the collector is in operation and the charging loop injects 83°C water into the tank. The volume above the inlet is heated. The temperature above the outlet at 19.5 meter actually decreases, which indicates that some mixing occurs in the top of the tank. The charging loop temperature increases and at noon it is $T23 = 85$°C. The water temperature above the 13.0 meter inlet increases uniformly. Furthermore, the volume below the inlet is heated more than can be explained by the net downward movement of the tank water. The injection of warm water in the vertical tube actually causes an additional upward flow in the tube that seems to be of the same order of magnitude as the injected flow. This additional upward flow must be balanced by downward flow outside the vertical tube. Charging of the tank continues with a decreasing inlet temperature. At 2 pm in the afternoon the inlet temperature is $T23 = 80$°C. During the day the DH return temperature increases and at 4 pm $T53 = 64$°C. From 8 am in the morning until 4 pm in the evening

57.6 GJ was collected, half of which was stored. Figure A.22 shows how the tank is discharged. At 6 am the store is depleted.
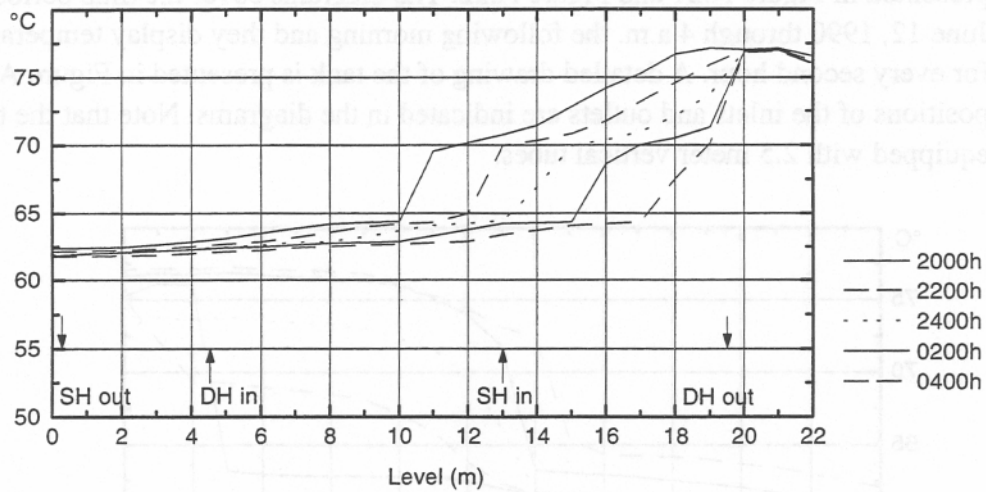
Figure A.22. Water temperatures of the accumulator when heat is leaving the store during the night between June 12 and 13 1990.

The over-all heat loss coefficient of the store was determined by a three week heat loss experiment in February 1992. The store was isolated from the loops and the steam boiler was off. An over-all heat loss coefficient UA = 160 W/K was found. Theoretically, the heat loss through the insulation and the foundation accounts for less than half of this UA value.

A.7 Economics of the CSHPDS

A.7.1 Investment

Table A.10 presents the price of the Falkenberg CSHPDS according to the tender of TeknoTerm, which was valid through February 1989. The CSHPDS was financed by a special loan to Falkenberg Energi AB from the Swedish National Council for Building Research. That loan is designed for full-scale experimental plants in the field of energy conservation and it covers almost the total investment.

Dividing the price of the CSHPDS 1.60 MUSD by the solar energy delivered to the DH network $Qs35 = 5.22$ TJ yields 0.31 USD/(MJ/a), which is the CSHPDS price per yearly MJ. This is a simple figure of merit that does not depend on assumptions regarding economic factors.

Table A.10. Actual price for the Falkenberg CSHPDS, excluding value added tax. (Price level of February, 1989. 1 USD = 7 SEK))

Item	kUSD	USD/m²
CSHPDS		
Solar collector array	1093	199
Pipe between array and the DH plant	243	44
Storage	264	49
Revamp and adjustment of consumer's substations	141	
Design, etc.	43	
Total price according to the tender of 1988	1785	292

It is interesting to monitor the history of the price of collector arrays. However, since the local conditions vary and there are only few arrays being built one need to account for the local conditions, the most important of which is the distance between the array and the DH plant. Thus, the price specified for the solar collector array supposedly include a functional array with the heat exchanger in one corner. This is the cost included in Table A.1 of Nykvarn I, Falkenberg, Nykvarn Odensbacken, and Säter.

A.7.2 Operation

Table A.11 presents an estimate of the yearly cost to currently operate the CSHPDS. This cost amounts to 0.6 per cent of the price of the CSHPDS and it adds 0.002 USD/MJ to the cost of the solar energy delivered to the DH network.

The utility company estimated that maintenance has required 100 man-hours per year. This includes looking over the array for leakage, tightening of fittings, checking the steam boiler, monitoring the water oxygen content, etc.

A.7.3 Comparison with Nykvarn I

Table A.12 presents a comparison between the investment cost of the CSHPDS at Falkenberg and Nykvarn I, respectively. The prices are adjusted to reflect the price level of

December 1991, which makes the prices in this table directly comparable with those in Table A.1.

Table A.11.   The yearly cost to operate the CSHPDS.

Item	USD
Personal, 100 man-hours	2858
Spare parts, glycol, etc.	2858
Electricity for pumps and steam boiler, etc.	4001
Rent paid for the property on which the array is located	915
Total yearly cost	10632

Table A.12.   Comparison between the CSHPDS investment price of the Falkenberg plant and that of Nykvarn I. All prices are adjusted according to the Swedish contracting price index E84 to be valid for December 1991 (Zinko and Dalenbäck, 1993).

The performance factors of the Falkenberg plant are averages for the three years 1990, 1991, and 1992. To facilitate comparison the price of the collector array at Falkenberg does not include the pipe between the array and the plant. The price per yearly MJ from the CSHPDS is based on the price of the CSHPDS alone. Concerning Nykvarn I, including the 1000 meter heat distribution pipe between the DH plant and the network adds 0.05 USD

Item	Unit	Falkenberg	Nykvarn I
Area of collector array	m^2	5,500	4,000
Volume of the storage tank	m^3	1,100	1,500
Total solar incident on the collector, $Q01$	MJ/m^2	4320	4183
The collector excess temperature, $Tdo01$	°C	49.9	48.1
Solar energy utilised, $Qs35$	MJ/m^2	950	1127
Price of collector array	USD/m^2	237	363
Price of CSHPDS	USD/m^2	348	488
Price per yearly MJ from collector loop	USD	0.25	0.33
Price per yearly MJ from CSHPDS	USD	0.37	0.43

Accounting for the operation conditions the thermal performance of the Falkenberg CSHPDS is approximately twenty per cent lower than that of the Nykvarn I CSHPDS. However, that is more than compensated for by the lower investment cost at Falkenberg. The price per square meter of the collector array is thirty-five per cent lower and that of the entire CSHPDS is thirty per cent lower. The latter figure does not include the thousand meter heat distribution pipe at Nykvarn. At Falkenberg the investment cost per yearly MJ from the collector loop and from the CSHPDS are twenty and twelve per cent lower than those at Nykvarn, respectively. However, when including the cost of the thousand meter DH pipe at Nykvarn the comparison shows twenty per cent lower investment cost for the solar energy from the Falkenberg CSHPDS.

A.8 Discussion and Conclusions

The main goal of the Falkenberg project is accomplished. The CSHPDS operates well and it exhibits a decrease in the cost of the solar energy compared to the best plants previously built in Sweden. The cost reduction is approximately twenty per cent.

A.8.1 Prediction of the collector performance

The long term thermal performance of the CSHPDS at Falkenberg is considerably lower than originally predicted by TeknoTerm. Misleading results from the module test is one reason to that. One used the Swedish standard (SS 1782, which is similar to the German standard DIN 4757) according to which the U-value is determined in the dark. This test method yields too low U-values leading to overly optimistic performance predictions.

A.8.2 The Teflon film convection barrier

The Teflon film convection barrier was the topic of an ongoing discussion throughout the project. Three of our observations are worth to mention.

- The Teflon film convection barrier exhibits malfunctions in many collector modules. Intermittently, it sags or it sticks to the outer cover. Moreover, the Teflon film has broken in a few modules.
- Visual inspection indicates that the convection barriers are in a better condition today after five years than they were a half a year after the installation. Shrinking might contribute to that.
- Convection barriers that initially look good may break after a couple of years. Thus, one cannot judge a mounting technique after a few months of operation.

The mounting technique of the Teflon film convection barrier needs further refinement.

A.8.3 The storage

Corrosion inside the storage tank is the most serious problem of the CSHPDS at Falkenberg. The arrangement to prevent entrainment of air into the tank does not work. A project that addresses these problems is underway.

To avoid crevice corrosion the tank must be perfectly airtight. Maintaining a small positive gauge pressure will indeed prevent entrainment of air. However, steam will enter the leaks, condensate, get in contact with outside air, and form an environment for crevice corrosion. Most likely, this is what happened at the safety lid of the storage tank.

The "stratifying enhancement device" in the tank do not work as intended. The device that consists of a wide vertical pipe (see Figure A.5) is mounted at the inlets of the tank. Measured temperature profiles show that the device causes a local mixing that involves water below the device. The temperature in the upper part of the device is noticeable lower (5-10K) than the inlet temperature. We understand that colder water from below is injected into the rising inlet flow. Outside the device a downward flow compensates for the injected water. The result is mixing.

A.9 Towards a lower DH return temperature

A low temperature level is beneficial to the thermal efficiency of a solar heating plant. In Falkenberg the return temperature of the district heating system was fairly high, and thus, to lower it, the consumer installations have been adjusted and in many cases revamped.

In this section we describe the project to lower DH return temperature, which was carried through in parallel with the solar heating project. The objective of the project was to lower the return temperature from 65°C, the prevailing level during of the years 1987 to 1989, to about 40°C.

A.9.1 Background

The DH system of Falkenberg includes a modern primary network to which several secondary networks of various standards are connected. The monthly mean values of the return temperature of the DH network were fairly high, around 65°C during the summer season of 1987. The July 1988 value was as high as 74°C. Figure A.28 presents monthly values of the load together with the supply and the return temperatures. Figure A.29 presents duration curves for the summer seasons of 1990 through 1992.

A.9.1.1 The district heating system ─────────

In Falkenberg the DH system delivers heat to 73 consumer substations, 53 of which are former block heating plants and 20 of which are consumer substations in single-family houses. The total yearly energy output is 100 TJ and the design load is 13 MW. The load consists of space heating, service water heating and losses from the network. No industries are connected and thus the summer load is low.

The DH plant comprises two wood-chips heated boilers (2+3 MW), two gas heated boilers, and the solar heating system. Natural gas is used for peak load.

The distribution network, built in 1985, consists 4900 m of distribution pipe buried 1.2 to 2.0 m below the ground surface. The distribution pipes are factory-fabricated and consist of a steel carrier pipe, a foamed-in-place polyurethane insulation and an outer polyethylene jacket. The yearly heat losses from the distribution network are approximately 4.3 TJ (1.2 GWh), which constitutes 5% of the total heat delivered.

A.9.1.2 Consumer installations

The consumer substations are of various designs. They range from simple prefabricated substations for single-family houses to substation serving blocks of larger houses. The smallest substations consist of heat exchangers, which produce service hot water and hot water for radiators and fan-coil units. The larger substations consist of heat exchangers, which heat the water of a secondary distribution network (we also refer to this as the local network). Connected to this secondary network are subcircuits, which divert hot water for radiators and fan-coil units, and service water heaters. Both storage and instantaneous type water heaters are used. The largest substation is found at an upper secondary school. It serves a secondary network, which includes approximately 50 subcircuits for space heating and service hot water heaters. These units are placed in attics, cellars and other small spaces in several houses. This school has a yearly heat demand of 9.4 TJ (2.6 GWh) and a maximum load of 1.6 GW.

The situation prior to switching to DH explains many of the specific configurations. The DH system replaced old block heating systems. A block heating system typically comprised an oil fired boiler, a distribution network and several subcircuits. Moreover, it was designed to operate at fairly high temperature level. The boiler was replaced by a new substation and the former block heating network became a secondary network. No measures were taken to decrease the return temperature of the local networks. The substations and the secondary networks are still owned by the customers.

Figure A.23 shows two typical configurations of consumer substations. The flow rate of the primary DH water is controlled according to control functions relating the flow rate to 1) the actual temperature of the service hot water, 2) the actual temperature of space heating water, and 3) the ambient temperature. High values of flow rates and return temperatures in the secondary network lead to high flow rates and high return temperatures on the primary side of the substation.
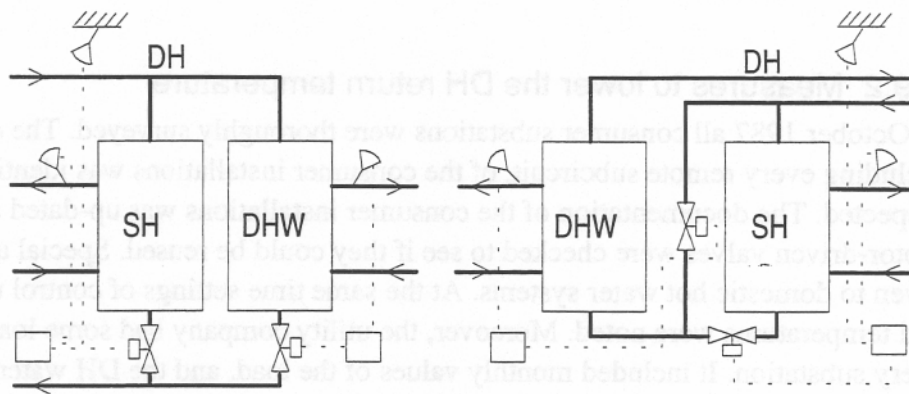
Figure A.23. Two typical designs of consumer substations.

Figure A.24 shows typical designs of subcircuits connected to the secondary networks of the large consumer substations. Several of these were designed as constant flow circuits; i.e. they take a constant high flow rate of hot water and divert the flow required to the target system. Consequently, when the load is small a large part of the hot water is fed directly from the supply pipe to the return pipe of the local heat distribution network.
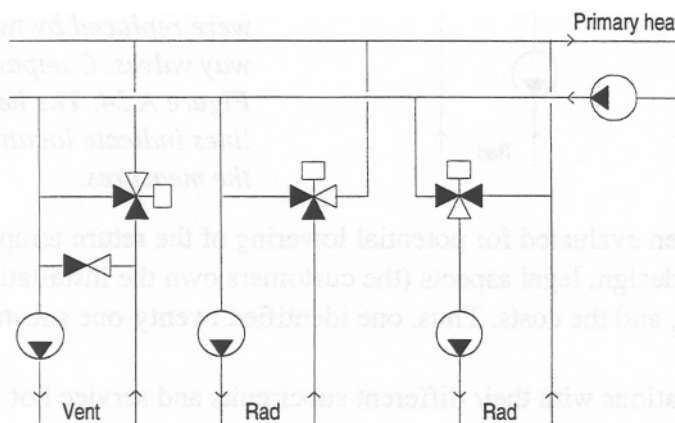
Figure A.24. Three subcircuits frequently applied in the consumer installations. The solid triangles of the three-way-valve symbol denotes ports, the flow rates through which are controlled.

Circuit	Primary heat flow	Terminal unit flow
left	constant	constant
middle	constant	variable
right	variable	constant

Figure A.25 presents a service hot water heater, which requires a constant high flow of DH-water.
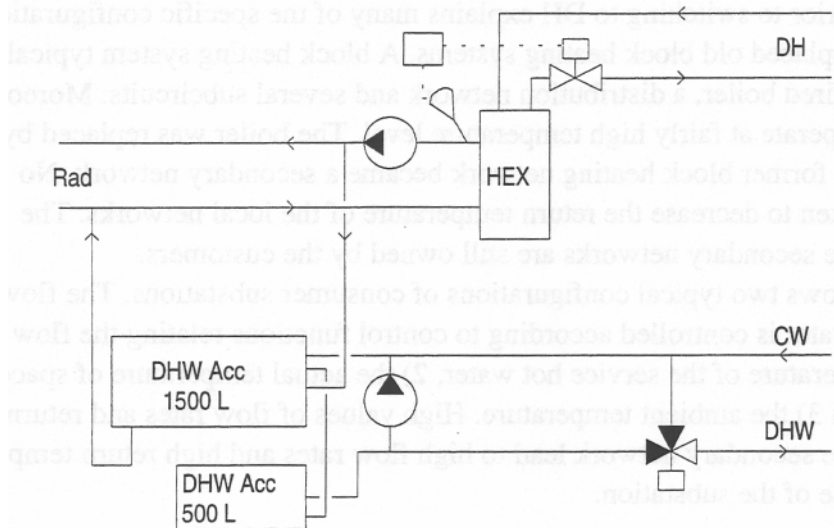
Figure A.25. Constant flow service hot water system in a consumer subsystem. (CW is cold water supply.)

A.9.2 Measures to lower the DH return temperature

In October 1987 all consumer substations were thoroughly surveyed. The equipment, including every remote subcircuit, of the consumer installations was identified and inspected. The documentation of the consumer installations was up-dated as needed. All motor-driven valves were checked to see if they could be reused. Special attention was given to domestic hot water systems. At the same time settings of control units, flow rates and temperatures were noted. Moreover, the utility company had some load statistics on every substation. It included monthly values of the load, and the DH water flow together with instantaneous values of the supply and return temperatures.
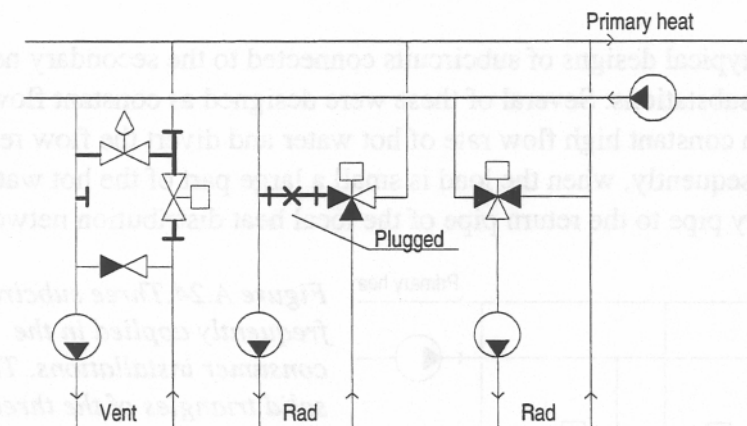
Figure A.26. Typical measures undertaken to lower the return temperature of substations with a local network. Three-way valves in subcircuits were replaced by two-way valves. Compare Figure A.24. The heavy lines indicate locations of the measures. *the measures.*

    The substations were then evaluated for potential lowering of the return temperature. One considered the actual design, legal aspects (the customers own the installations), the operating conditions noted, and the costs. Thus, one identified twenty-one substations, which needed a revamp.

    These twenty-one substations with their different subcircuits and service hot water heaters were subsequently revamped in the autumn 1989. Three-way valves were plugged in order to work as two-way valves. Due to age, leakage, etc., this was not always possible. In some cases they had to be replaced by new two-way valves. In several cases the valve motor had to be replaced as well. Moreover, one or more temperature-controlled by-pass valves were installed. These valves permit a small circulation in the system at times when

there is no demand for space-heat or domestic hot water. Then when there is a sudden demand for heat the circulated water will be warm enough to deliver heat at once.

Whenever possible, existing constant flow storage type water heaters were replaced by instantaneous type water heaters directly connected to the DH network.

In September 1990 some substations were inspected, since the overall result of the measures taken so far was poor. Adjustments were made in the substations, which solved most problems. However, one identified another three that needed to be revamped, which was done in the summer 1992.
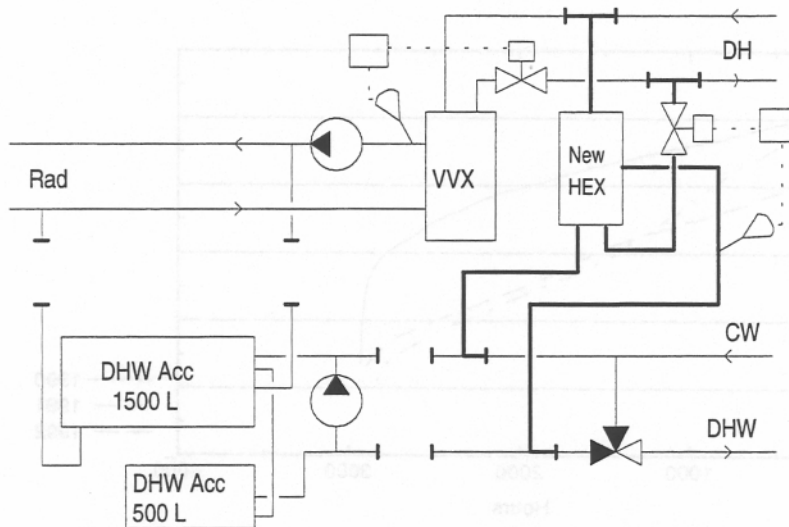
Figure A.27. A new heat-exchanger for domestic hot water (DHW) directly connected to the DH network. Compare Figure A.25.

A.9.3 Results

After the revamp of the substations the return temperature of the district heating system was approximately 10°C lower than before. During a large part of the year the monthly mean DH return temperature is now around 52 - 53°C, but during summer it still rises to over 60°C in July. This was more than 10°C higher than expected. Figure A.28 and Figure A.29 summarise the results.
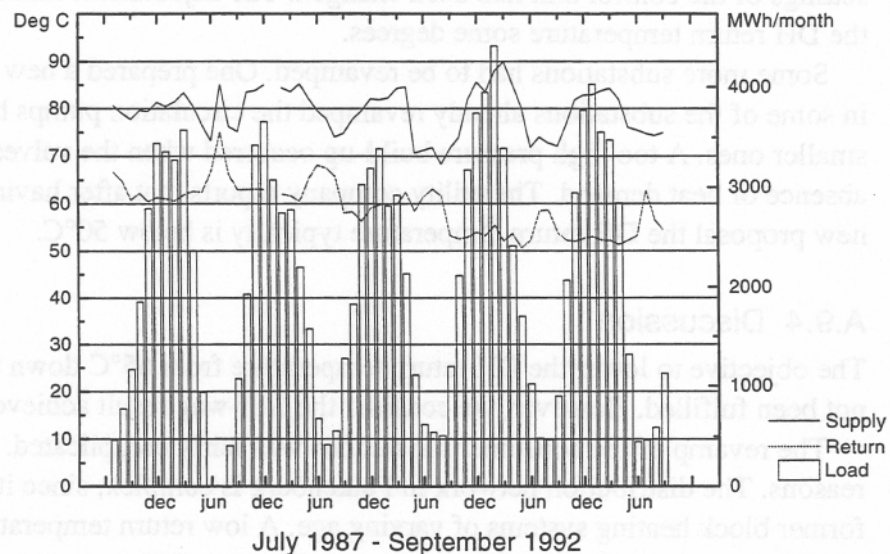
Figure A.28. The return temperature has been lowered since autumn 1989.

The reduction of the return temperatures of the consumer substations achieved improves the energy efficiency of the overall system. The heat loss of the DH network decreases and the performance of the collector array increases. We estimate that the two gives a yearly saving in the required boiler output of 0.7 + 0.7 TJ (0.2 + 0.2 GWh). Furthermore, there is a yearly saving in electric energy for pumping, which conceivably is in the range of 0.5 TJ.

The cost of the design, revamp, and adjustments of the consumer installations was 0.17 MUSD (Terms of February 1989). Thus, the investment cost per yearly MJ was 0.09 USD.
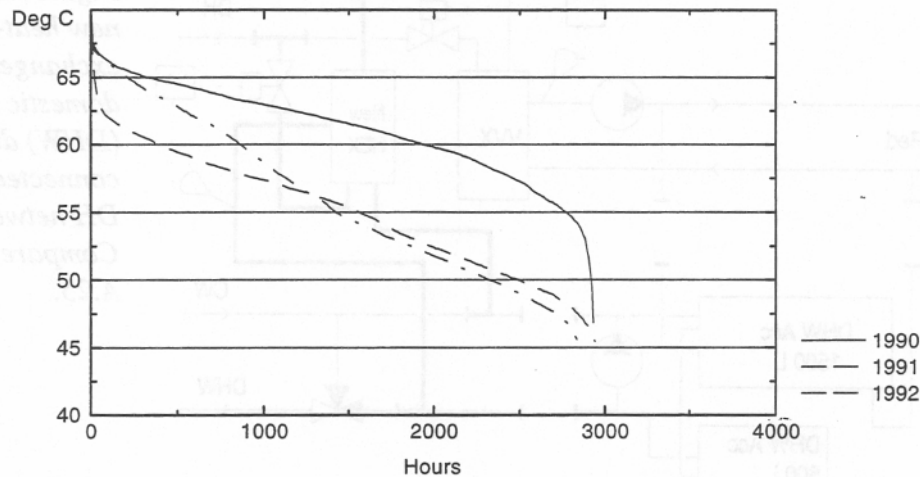
Figure A.29. Duration curves of the return temperatures of the district heating system during May to August 1990 - 1992.

A.9.3.1 Further measures to lower the DH return temperature

After the end of our monitoring period there has been at least one more detailed survey of the consumer installations. Every substation was checked on-site. One observed that in several places the revamp of the installation was not made as intended. In some cases the settings of the control unit had been changed. The adjustments made at this time lowered the DH return temperature some degrees.

Some more substations had to be revamped. One prepared a new proposal. Moreover, in some of the substations already revamped the circulation pumps had to be replaced with smaller ones. A too high pressure build-up occurred when the valves were closed due to absence of heat demand. The utility company reports that after having implemented the new proposal the DH return temperature typically is below 50°C.

A.9.4 Discussion

The objective to lower the DH return temperature from 65°C down to around 40°C, has not been fulfilled. However, we consider the half-way result achieved to be respectable.

The revamp of the consumer substations was fairly complicated. There are several reasons. The distribution network in Falkenberg is complex, since it includes several former block heating systems of varying age. A low return temperature was never a requirement in the design of these systems. The new DH system was adapted to the old block heating systems rather than the other way round. Moreover, the customers own the substations and the local networks. The documentation was not always up-to-date.

However necessary, the on-site survey of the consumer installations and the up-dating of the documentation of the is a tedious job. The risk to over-look some installations is large. In our project there is anecdotical information on short-cuts between the return and the supply pipes caused by supposedly closed valves, with the handle in the close position.

Replacement of three-way valves by two-way gives the intended thermal function. However, it also raises the pressure downstream the pump, which in some cases have caused noise and leakage. The circulation pump had to be replaced in some cases. Moreover, it may cause problems with too low temperatures of the domestic hot water directly after periods with no consumption.

In Falkenberg the customers are not charged for the total heat carrier and thus is not rewarded for a low return temperature. Charging both for the energy and the flow would make the customer more interested in the performance of his installation.

A.9.5 Conclusions

The main conclusions are

- A considerable decrease of the DH return temperature was achieved by revamp and adjustments of the consumer substations and local networks.
- The investment cost to lower the return temperature was 0.09 USD per yearly MJ (February 1989, 1 USD = 7.0 SEK).
- A comprehensive on-site survey of the consumer installations is a prerequisite to the design of a revamp.
- Checks and adjustments of the consumer installation on a regular basis are essential to maintain a low DH return temperature.
- A good co-operation with the customer is crucial. The legal aspects must be considered.
- A few short-cuts between the supply and the return may have a large impact on the return temperature. They may appear in unexpected places.

A.10 Literature

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APPENDIX B: PROJECT DESCRIPTION OF THE GÖTTINGEN CSHP-PROJECT (GERMANY)

The Göttingen Solar District Heating Project

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B 1. Summary

Large scale collector installations show the inherent potential of cost effectivity. The paper describes the installation of a roof-integrated collector system on a powerplant building, which is connected to the return flow of the communal district heating network in Göttingen/Germany. The system combines moderate installation and operation costs with a high expected yield, is monitored continuously and investigated in detail within an extensive research program. The design characteristics are discussed and first results presented.

B 2. Introduction

B 2.1   Large collector systems in Germany

In the last 20 years the development of solar thermal energy in Germany has been determined by small collector systems for domestic hot water in detached family houses. Although these systems deliver about 50 % of the domestic hot water demand in a year, referring to the whole heat requirement in a house the contribution is only a few percent.

In Germany today about 40 % of the national energy consumption is caused by the heating load of domestic hot water and space heating systems. In order to cover a considerable part of this energy demand by solar energy it is absolutely necessary to build and to investigate the potential and performance of solar assisted heating systems with or without seasonal storages.

Based on the experience gained in Sweden and Denmark since the midst of the eighties, several investigations and demonstration projects concerning CSHP-systems have been carried out in Germany. As a result of these activities, different pre-studies proved, that there is an enormous potential of this technology in Germany.

As the German government supports a step-by-step philosophy in the area of research and development, different CSHP-projects have been put into action in order to gain experience from large collector arrays and their integration in central heating plants. The 'Göttingen Solar District Heating System' builds one of these projects.

In order to stimulate progress in this technology in 1993 a national research and demonstration programme called 'Solarthermie 2000' has been set up. In this programme, which will be carried out from 1993 to 2002, different CSHP-systems will be supported and about 100 million Deutschmark will be available.

B 2.2   The Göttingen Solar District Heating Project

B 2.2.1   Initialization

The 'Stadtwerke Göttingen AG' are a typical local utility in Germany which supplies heat, water and gas to their consumers in the town of Göttingen. Furthermore the local public transport is a part of their field of activities.

In spring of 1990, first ideas grew in the Stadtwerke Göttingen AG to use renewable energies - especially solar energy - in the central cogeneration plant, which is placed in the centre of Göttingen. At the same time, a renovation of the building of the combined heat and power system has been decided.

These two main reasons led to the decision of the local utility of Gottingen to develop in co-operation with the two German institutes ISFH and ITW a concept for the use of solar energy in the existing cogeneration plant. Based on a feasibility study comprising ISFH and TRNSYS simulations in 1992 the German ministry of research and development decided to support this project which was included in the national programme: 'Solare Nahwärmekonzepte'.

The evaluation program is sponsored by the Federal ministry of research and development. The investment cost of the solar system is shared between the State Ministry of Trade and Commerce of Niedersachsen (Lower Saxony) and the Stadtwerke Göttingen AG.

For the co-ordination of the different activities of the project, a special steering committee was founded in which the following members:

Stadtwerke Göttingen AG,

ISFH Institute for Solar Energy Research Hameln / Emmerthal GmbH

ITW Institute for Thermodynamics and Heat Engineering University of Stuttgart

act as co-operating partners. The main aims of this committee consist in

▶ structuring of the different activities and tasks,

▶ co-ordination of the scientific research programme,

▶ solving of problems that occur during project running time, and

▶ project presentation within the national and international framework.

B 2.2.2 Realization

The official start of the Göttingen Solar District Heating project was in May 1992. During summer of 1992, remaining technical details as e.g. the lowering of the return temperature had to be clarified. Installation work began in August 1992. Table 1 presents the different installation phases of the two collector systems and the measuring system.

Both of the solar installations, the flat plate collector system as well as the 'Solar-Wall' air collector system required some preparatory work directly linked to the renovation of the power plant building. The work started with the dismantling of the Eternit sheets (i.e. corrugated asbestos-cement plates) on the large east roof according to actual health and safty regulations, taking more time than assumed preliminarely. After dismantling, the roof had to be completely covered with a plastic foil in order to prevent the power plant installations in the building from rain. Also the facade had to be dismantled from Eternit corrugated sheets and be prepared for the installation of the air collector system. The roofs of the turbine hall had been in a good shape so that only some minor repair works had been necessary.

In the beginning of September 1992 the collector manufacturing company (SOLVIS Energietechnik, Braunschweig) started the mounting of the flat plate collector modules on the large east roof. Because of the height of the building, a big crane had been used to lift the collector modules and put them in the prepared places. The

installations on this roof including the piping connections between the modules had been finished at the end of October.

The mounting of the collectors on the two small roofs turned out to be more easy because of the flat slope of these arrays it was possible to carry about 8 collectors in one package on the roofs. These installations took about 3 days and had been finished in the beginning of November.

In parallel, the installations of the 'SolarWall' air collector system started in August. The outside construction work, including the transpired air-facade, of this collector system ended in the middle of November. The construction inside the building including the ventilation ductwork between the air collector sections and the conventional combustion air inlet to the gas burners had been finished in the third week of January 1993.[1]

The piping installations of the flat plate collector system started in the middle of November and lasted until end of February 93. During this time, the gasketed-plate heat exchanger connecting the solar and the conventional system had been mounted. Finally in February the installation of the control unit had-been carried out.

Timetable Installation work 1992 / 93										
	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb..	March	April
Flat plate collector system										
Collector installations			▓	▓						
Piping installations					▓	▓	▓	▓		
Insulation work						▓	▓	▓	▓	
Heat exchanger install.						▓				
Control system install.								▓	▓	
Filling									▓	
Commissioning									▓	
SolarWall air collector system										
Collector installation		▓	▓	▓	▓					
Ventilation pipe install.				▓	▓	▓	▓			
Control system install.						▓				
Commissioning									▓	
Measuring system										
Sensor installation					▓	▓	▓	▓	▓	
Measure-value logger						▓	▓	▓	▓	
Commissioning									▓	

Table B-1:   Timetable of the installation work

1 For further information about the 'SolarWall' air collector please notice the final report of IEA Task 14 air collector system group.

At the 5th of March the collector system had been filled with a water / propylene glycol mixture and the system had been operated for the first time. The commissioning of the flat plate collectors took place in the middle of the march 1993.

In general, installation work took place under rather hard working conditions: the team of the collector manufacturer had to face sometimes rainy and stormy autumn weather conditions, making the work on the slipery plastic foil on the roof rather difficult; inside the building, heat losses in the building, heat losses of the power plant installations caused ambient temperature to raise up to 50 °C, - partly caused by the improved air-tightness of the building after renovation.

The installation of the measuring system had been carried out between the beginning of December and the end of February. These works included the installation of the sensors, cable ducts and cable connection boxes as well as the commissioning of the data-logger in combination with a personal computer.

Some days before end of 1992, the data acquisition programme developed by ISFH and the associated hardware had been operated the first time. Because it operated without any problems right from the beginning, it had been used in the installation phase for the testing of new sensors and cabling. Also, it turned out to be of great help for collector loop installers and powerplant technicians to have temperature, radiation and volume flow readings on-line available during the test and the commissioning of the solar systems.

B 2.2.3 Objectives

The main objective of the Göttingen Solar District Heating project consists of the technological and economical improvement of large solar systems, equipped with high-performance, roof-integrated collectors.

It is the overall objective of this project to demonstrate that solar energy applications for district heating systems show several advantageous features:
► both the installation and the operational costs are moderate;

    temperature, continuous summer operation and reduced specific piping losses.)

In order to achieve these goals the main features of the workplan are
► detailed recording and analysis of the operational and energetical behaviour of the system;
► optimization of the operational strategy for maximum system output;
► validation of several types of short term test methods capable to provide long term system output prediction;
    ▶ in-situ verification of the predicted collector array yield in large collector systems using the Input / Output methods;

▶ detailed investigations of the relationship between standard collector efficiency test results and in-situ collector array efficiency;

▶ investigations of the potential of cost-reduction by large solar systems with respect to individual solar energy systems.

B 2.3   District heating systems in Germany

In Germany today, district heating enjoys a high status because it supplies approximately 10 % of the market. In the western states, around 70 % of the heat distributed by networks originates from cogeneration, in the eastern states the race to catch up with combined generation is in full swing.
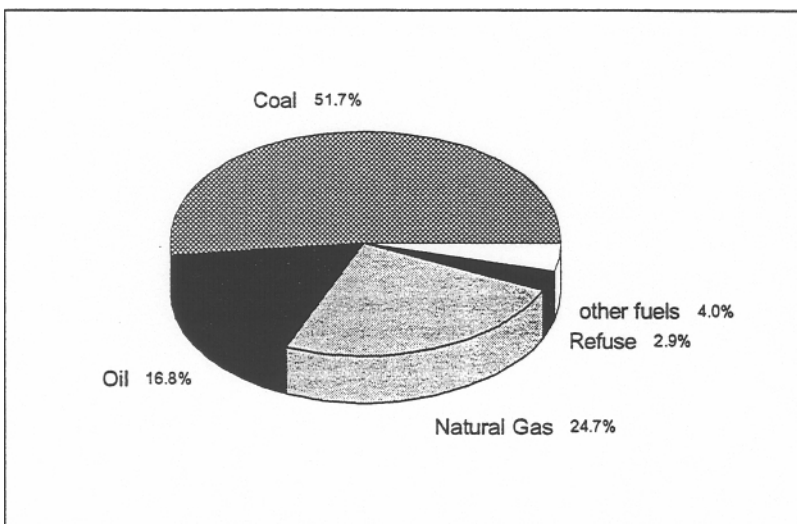
The main carrier of West German district heat production is hard coal and in the new federal states brown coal. The Figure besides gives an impression about the fuels used for heat generation. In addition it has to be mentioned that heat production systems in city centre areas mainly operate on natural gas.

B 2.3.1 Network temperatures

In German district heating networks the supply and return temperatures vary in a wide range but most systems operate with maximum supply temperatures of about $t_{NV} \sim 120\,°C \ldots 140\,°C$. Because of that "high-temperature state of technology", low temperature networks have not been a central issue in Germany for a long time.

Only in the last few years the discussion about this subject grows. A few local utilities set up different programmes and developed new concepts aiming at the optimization of their network operation within the context of the rational use of energy. These concepts include both lower supply and return temperatures as well as changes of control strategy and modifications of the consumer substations.

Two mayor issues will be treated in the future:

district heating networks has the advantage, that the networks do already exist and investments are needed just for the renovation/modernizing of the operating conditions. The advantage of this concept is twofold: reduced operating temperatures improve

both the conventional summer and winter performance of the network itself as well as the performance of the solar system. Furthermore, within this case, the oecological image of solar energy utilisation can help in fund raising for renovation of conventional energy systems.

the integration of large solar collector systems into **new** district heating networks will benefit of course from the low operating temperatures of new networks (which should be made mandatory). But in this case, the solar option depends on the readiness to invest into both the solar system and the network.

More comparative studies will be needed to analyse these two options of solar energy utilisation.

B 3. The central solar heating plant CSHP Göttingen

B 3.1   Flat plate collector system

B 3.1.1 Collector modules

The flat plate collector system consists of roof-integrated, high performance flat plate collectors with selective absorber (black crome on copper). The single glazed collector modules are equipped with a 50 μm Hostaflon foil as convection barrier, fixed between absorber and glass by a special stretching and clamping technique. Furthermore, steel wires stretched by springs maintain the optimal distance between absorber and foil.

The collector consists of absorber fins connected in parallel. Most collector modules have a size of 6.0 m^2 or 7.5 m^2, also smaller modules have been installed in order to cover the whole roof area.

Collector efficiency measurements have been carried out by different institutes in Germany and in Switzerland. The investigations at the ISFH based on the ISO-DIS 9806-1 gave the following experimental results (referred to the absorber area):

$$\eta_0 = 0.758 \qquad a_0 = 2.88 \frac{W}{m^2 K} \qquad a_1 = 0.013 \frac{W}{m^2 K^2}$$

1	slot for glass cover	9	30 mm PU foam sheet
4	collector box frame	10	EPDM rubber sealing
5	thermal barrier	11	high transparency glass cover
6	screw connection	12	glass grider section
7	two-coat insulation with	13	selective black crome coating
	40 mm rock wool	14	copper heat conduction sheet
8	distribution pipe	15	copper pipe
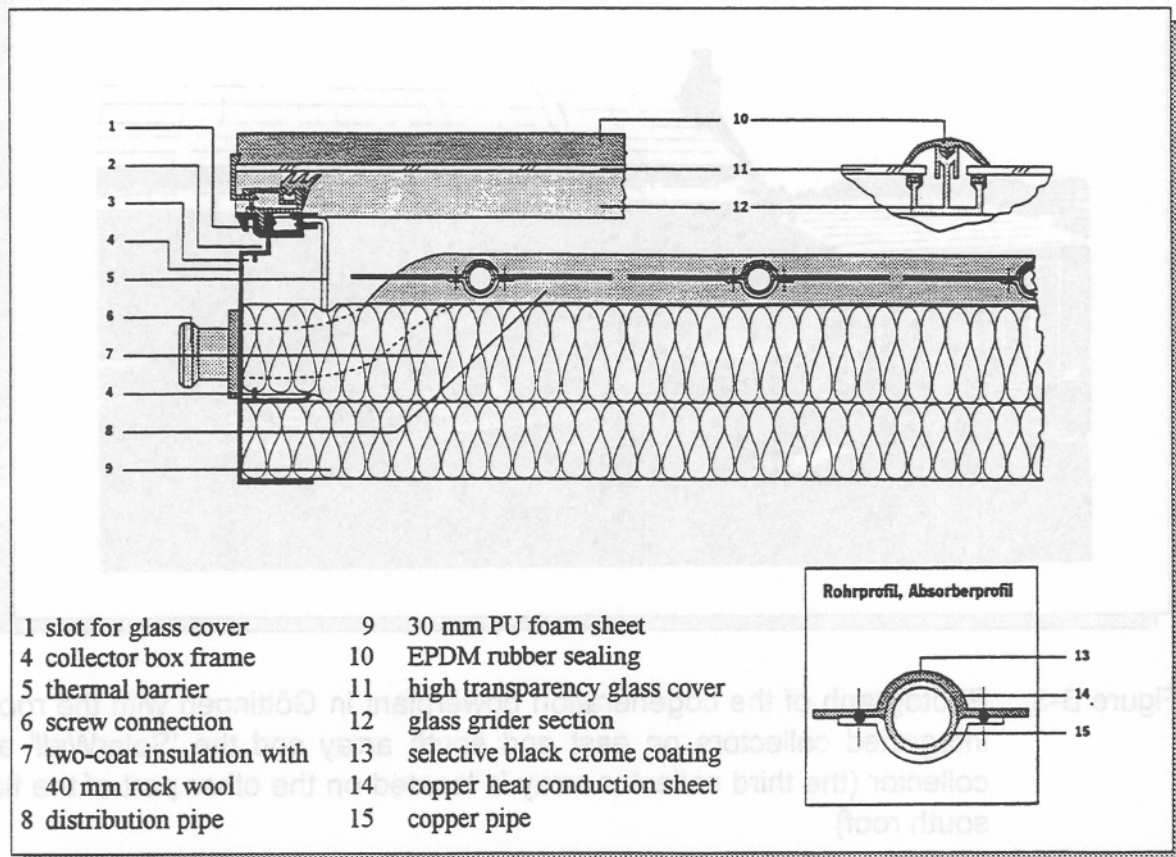
Figure B-2: Cross sectional view of a typical Solvis flat plate collector

The cross sectional view in figure B-2 shows in details the construction of a typical Solvis flat plate collector that has been installed in the Gottingen project, only the anti-convection foil and the steel wires are not shown in the drawing. It has to be mentioned that the collector type used in this research and demonstration system is the first one from the Solvis company that has been equipped with a foil as a convection barrier. The positive operational experience from the 3 years monitoring period proves, that the way of fixing the foil inside the collector seems to be very promising. This subject is of growing interest because in many other cases experiences with foils inside a collector have not been very good.

B 3.1.2   Solar collector arrays

Figure B-3 presents a photograph of the cogeneration powerplant building in Göttingen, showing the roof-integrated collector system and the 'SolarWall' air collector as viewed from south.

Figure B-3: Photograph of the cogeneration powerplant in Göttingen with the roof-integrated collectors on east and south array and the 'SolarWall' air collector (the third collector array is located on the other part of the flat south roof)

Following two mayor project goals, i.e.
> ▸the use of available roof area as an alternative to ground based collector arrays
> ▸the test of building integrated collectors,

one important task of the pre-design phase computer simulation studies carried out at the ITW Stuttgart was to select all suitable roof parts in order to deliver as much solar energy as possible together with a high level of collector performance.

As a result of these studies, Table B-2 gives the characteristical data of the three collector arrays: orientation, slope and collector area. The largest collector field (455 m^2) is located on the south-east (E) roof with a tilt angle of 32°. The small arrays are located on the north-west (W) and the south-east (S) roof with a tilt angle of 17°, aperture areas are 162 m^2 for array W and 168 m^2 for array S. (Because of the "off-south" orientation of the building, the collector arrays are designated East, South and West according to the direction of their diagonal).

Collector array	Collector area [m²]	Tilt angle [°]	Azimuth angle [°]	Number of modules
East	455	32	-58	56
South	168	17	-58	28
West	162	17	122	28
Total	785			122

Table B-2:   Characteristical data of the three collector arrays

The available irradiation and resulting collector performance is presented in Table 3 for each of these collector arrays based on TRNSYS calculation executed at ITW Stuttgart /Guigas92/ assuming a return temperature of 40 °C.

Collector array	Collector area [m²]	Annual Irradiation kWh/(m²a)	Annual Collector array Output kWh/(m²a)	Collector array efficiency [%] (Treturn 40 ˚C)
East	455	984	389	39,5
South	168	971	379	39
West	162	857	288	33,6
Total	785	952	365	38,3

Table B-3:   Irradiation and Collector array performance
             (based on Return temperature 40 ˚C)

Due to the relatively flat roof slope of the south building annex (see Fig. 3), the difference in irradiance between the "south" and the "west" arrays are only 13 %. However, as will be discussed in chapter C 6.3, the suitability of differently oriented surfaces depends not only on the orientation itself but also on the operating temperature in the system.

B 3.1.3 Solar collector loops

The east array is arranged in 9 parallel rows with 7 collector modules connected in series. In both of the smaller collector arrays (south and west), 4 rows are connected in parallel, were 3 rows have 8 modules and 1 row has 4 modules connected in series. There is no Tichelman connection used because the individual collector modul rows have been designed to have a pressure difference about 10-times larger than the delta-p of the distribution pipes to the arrays. There have been no problems with flow balancing in the collector arrays.

As described before, the hydronic system consists of three collector arrays, which are installed in individual, parallel loops and branched to one central heat exchanger, coupling the solar system to the return pipe of the DH network.

In the collector system a propylene glycol / water mixture in a ratio of 33 % to 67 % is used as heat transfer medium. Each collector array loop is equipped with a separate pump in order to reach the optimal flow rate of about $50 \frac{kg}{m^2 h}$ in each collector loop. Furthermore the flow rates in the separate collector loops have been adjusted in order to reach similar temperature increments between supply and return flow in the different loops.

B 3.1.4 Solar control system

The different inclination and orientation of the three collector arrays require three independently controlled collector array loops which operate according to separate delta-T controllers based on the actual differences between the absorber and the return temperatures in the distribution network. Figure B-4 to B-6 indicate the control strategy for the three collector arrays to switch the pump on, figure B-7 shows the switch off condition.

The control units of the three collector arrays operate with the same switch on criteria: the circulation of the collector loop starts when the absorber temperature in one special collector module (one for each array) is 5 K above the return temperature in the district heating network. The collector array pump stops operating when the collector loop outlet temperature (close to HX inlet) of the corresponding loop is 1 K above the outlet temperature of the HX. Thus, energy stored in the thermal capacity of the collector loop fluid is used as long as possible.

Between switch on and switch off of the collector loops there is a time difference of 6 minutes. That means, that after circulation starts it takes 6 minutes until the control unit begins to check the switch off criteria stated above. This operating mode has been chosen to avoid to much pump cycling which will occur due to the high heat capacity of each collector loop.
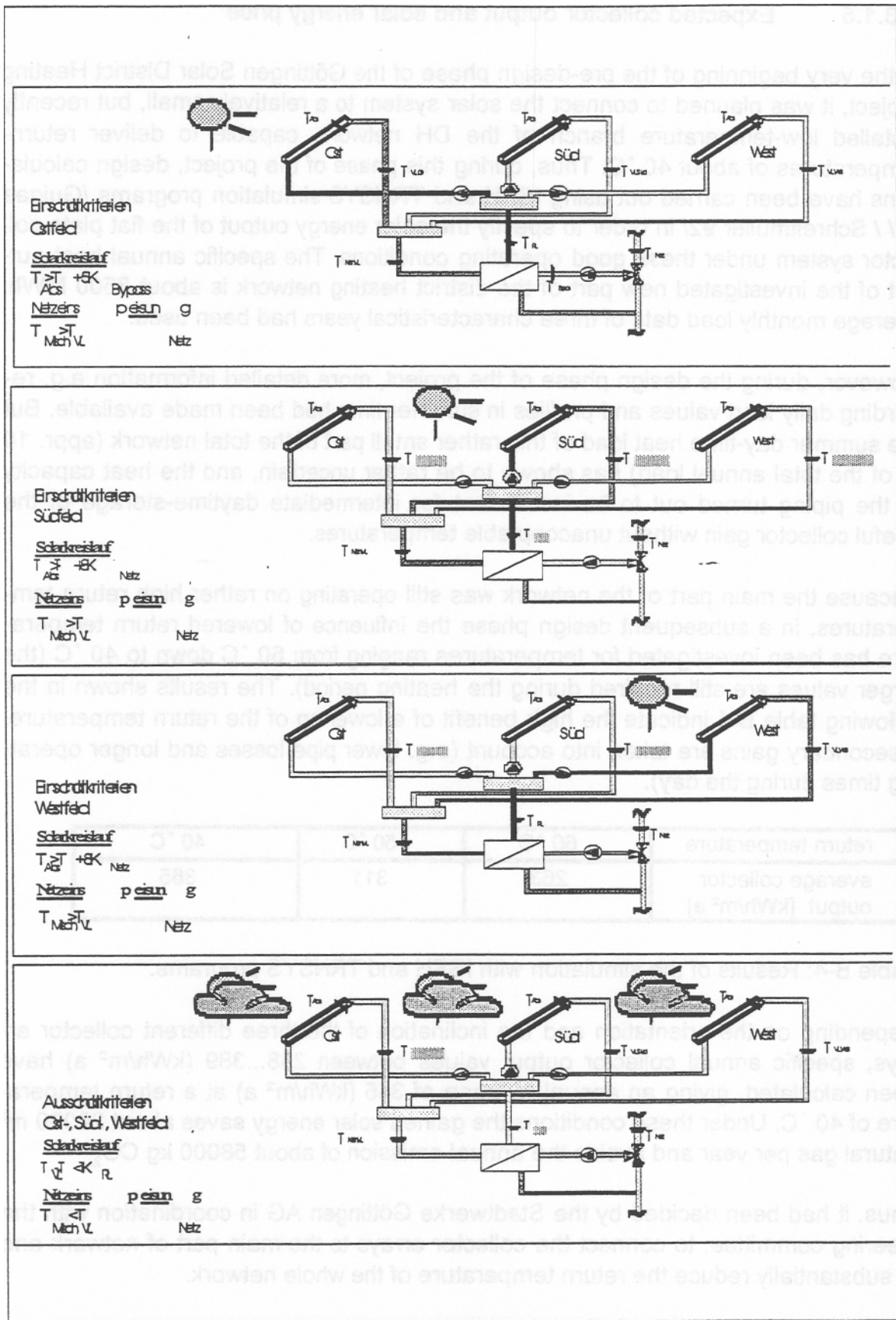
Figure B-4 .. B-8:   Switching criteria for the three collector loops

B 3.1.5   Expected collector output and solar energy price

In the very beginning of the pre-design phase of the Gottingen Solar District Heating project, it was planned to connect the solar system to a relatively small, but recently installed low-temperature branch of the DH network, capable to deliver return-temperatures of about 40 °C. Thus, during this phase of the project, design calculations have been carried out using ISFH and TRNSYS simulation programs /Guigas 92/ / Schreitmüller 92/ in order to specify the solar energy output of the flat plate collector system under these good operating conditions. The specific annual heat output of the investigated new part of the district heating network is about 8500 MWh; average monthly load data of three characteristical years had been used.

However, during the design phase of the project, more detailed information e.g. regarding daily load values and profiles in summer time had been made available. But the summer day-time heat load of this rather small part of the total network (appr. 10 % of the total annual load) has shown to be rather uncertain, and the heat capacity of the piping turned out to be insufficient for intermediate daytime-storage of the useful collector gain without unacceptable temperatures.

Because the main part of the network was still operating on rather high return temperatures, in a subsequent design phase the influence of lowered return temperature has been investigated for temperatures ranging from 60 °C down to 40 °C (the larger values are still required during the heating period). The results shown in the following table B-4 indicate the high benefit of a lowering of the return temperature, if secondary gains are taken into account (e.g. lower pipe losses and longer operating times during the day).

return temperature	60 °C	50 °C	40 °C
average collector output [kWh/m² a]	263	311	365

Table B-4: Results of the simulation with ISFH and TRNSYS programs.

Depending on the orientation and the inclination of the three different collector arrays, specific annual collector output values between 288...389 (kWh/m^2 a) have been calculated, giving an annual average of 365 (kWh/m^2 a) at a return temperature of 40 °C. Under these conditions the gained solar energy saves about 29000 m3 natural gas per year and avoids the annual emission of about 58000 kg CO_2.

Thus, it had been decided by the Stadtwerke Göttingen AG in coordination with the steering committee, to connect the collector arrays to the main part of network and to substantially reduce the return temperature of the whole network.

The simplified system concept and the cost reduction of large collector modules lead to specific system costs of 396 US$/m^2 (640 DM/m^2). Together with the high specific system output, a solar energy price of about 36 US$/GJ (21 Pf/kWh) has been

calculated, based on a lifetime of 20 years, an annual interest rate of 8 % and a share of 1.5 % for operational and maintenance costs.

If the 50 % subsidy granted for that demonstration project by the Ministry for Economy of the Federal State of Lower Saxony (Niedersachsen) is taken into consideration, the cost/performance ration of about 18 US$/GJ (10.5 Pf/kWh) would be rather close to the conventional cost of the DH-System of Stadtwerke Göttingen 14 US$/GJ (8 Pf/kWh).

This shows, that further improvements in the cost/performance ratio are needed in the future.

B 3.2   Co-generation plant Göttingen

B 3.2.1 Combined heat and power

Since the first years of the 60'ies, the Stadtwerke Göttingen AG operate a district heating network and from the early beginnings combined heat an-d power generation has been their main interest. Due to the economical and ecological advantages of this technique the district heating systems grows very fast and until today many modifications have been accomplished.

In 1992 the cogeneration powerplant consists of two high-pressure superheated-steam boilers with two subsequent steam turbines delivering a maximum power output of 5 MW$_{el}$. Furthermore, two high-pressure steam boilers are installed in order to cover on-peak consumption in winter and for the low-load period in summer. The whole available heat capacity in the cogeneration plant is about 65 MWth.

B 3.2.2 District heating network

The distribution network of the local utility of Göttingen has a length of 12 km and in the city area about 140 large buildings are supplied with thermal energy. Between May and September the district heating power station only produces thermal energy whereas the cogeneration mode is restricted to the space-heating period.

B 3.2.3 Energy load

First pre-studies of the Göttingen project were made under the condition that only a small part of the whole DH network that operates with lower temperatures of about 40 - 50 °C in the return flow should be connected to the solar system. But in the realization phase it was recognized that the return flow in this small network wouldn't be big enough to take up the solar energy in summer. So it was decided to connect the solar system to the main DH network and to lower its return temperature to approximately 40 °C.

The annual heat demand in the main DH network is approximately 100.000 MWh in which the summer load between May and September is less than 15 % of the total annual load. During the monitoring phase of the project, return temperatures have already been reduced. Actually, the return temperatures in the network vary during the year between 65 °C and 75 °C depending on the ambient temperature and the combined heat and power mode.

B 3.3 Solar system integration

The simplified scheme in figure B-9 shows the integration of the three collector arrays into the co-generation plant. The three parallel collector loops are connected via a heat exchanger to the return flow of the distribution network in order to preheat the return flow of the district heating network. The nominal rating of the gasketed-plate heat exchanger is about 600 kW based on a volume flow rate of V = 40 m3/h and a temperature difference of ΔT = 12 °C.
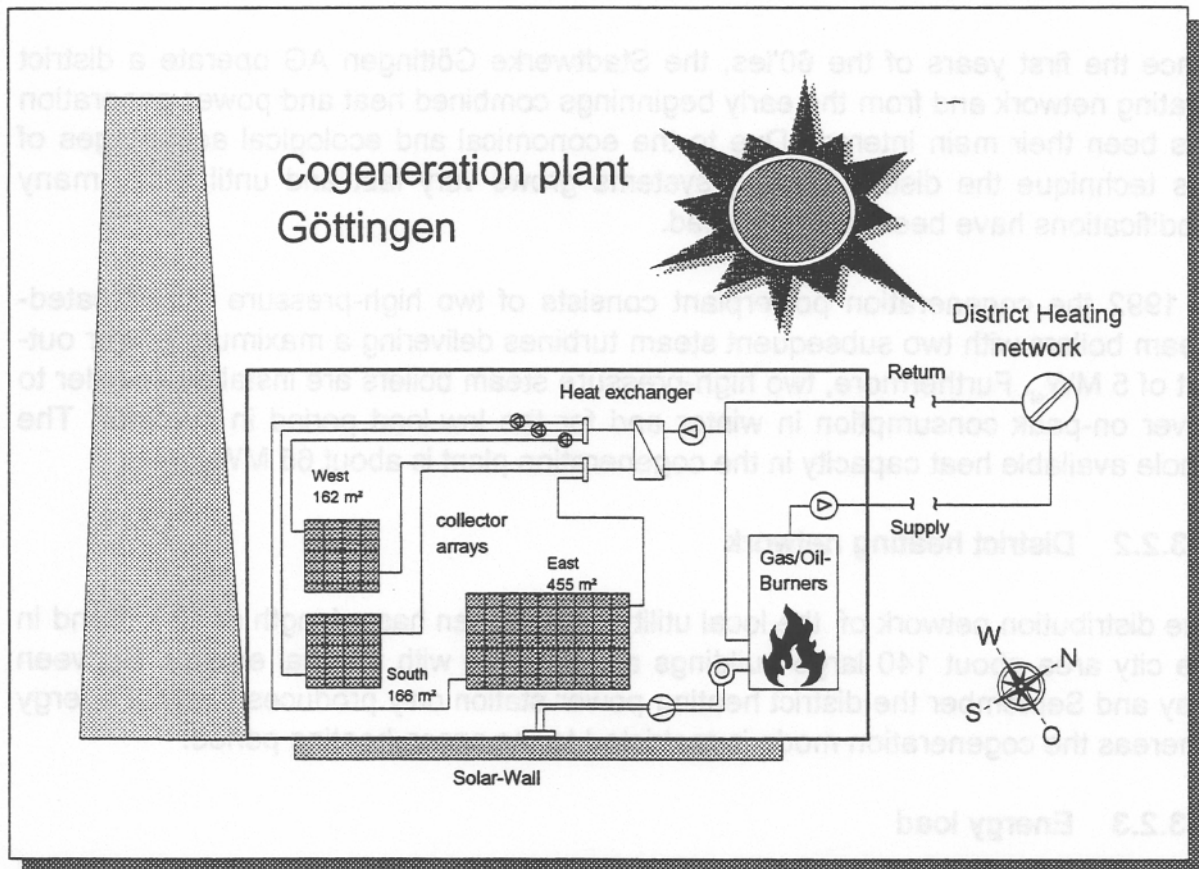
Figure B-9:
Simplified scheme of the solar systems integration into the cogeneration powerplant

The flow rate on the network side of the solar heat exchanger is controlled by a separate unit that operates in dependency of the mixed outlet temperature of the three collector loops and the network return temperature. Circulation on the network side starts if the difference between these two temperatures is above 1 K.

B 4. Operation and maintenance

The Göttingen CSHP was installed between September 1992 and March 1993. The commissioning took place end of March 1993. Since then, the collector system operates without any major problem and still is in operation until today.

B 4.1 Operational experience and malfunctions

In view of the fact that the Göttingen solar system is the first pilot plant for large solar collector arrays in Germany and still is the largest project until today only a very small number of problems occurred during three years of operation. It can be stated that most problems are a result of the high temperatures in the distribution network.

B 4.1.1 Collector system

In the first period of operation it took some weeks to remove some condensate from the collectors that has been penetrated into the modules during the very rainy installation time of fall and winter '92. Afterwards this problem didn't occur any more.

According to visual inspection, the collectors are in a very good shape despite some broken steel wires inside the modules. The most noticeable thing is the large extent of soiling on the cover glasses in comparison to other collector systems that are placed in the countryside.

Till autumn 1995 only one leakage occurred in a safety valve caused by a failure of a control unit in the east collector array which caused temperatures to raise above 100 °C in the collector loop. Despite this failure no working fluid has been lost during operation time. Furthermore two glass covers in a collector module were loosened by storm and had to be refixed into the collector frame.

Some problems occurred in the roof integration concerning the rain tightness of the collector arrays. In the small collector fields it is solved but in the large east collector array it is not yet clear how to tighten some minor parts of the collector roof.

B 4.1.2 The Hostaflon film convection barrier

The Hostaflon foil which is used as a convection barrier in the modules caused no problems even in the collectors where the steel wires are broken. By visual inspection no degradation, deformation or lengthening can be observed, leading to the conclusion that the way the Solvis company fixed the foil into the collector module seems to be a very good solution.

In August 1995 a small piece of the Hostaflon foil has been cut from a collector in order to carry out investigations concerning any kind of degradation of the foil.

B 4.1.3 Collector control system

In the beginning of the operation time the main objective was to analyze the function of the chosen control strategy. A first check during commissioning of the three collector array loops indicated, that the control units performed as expected.

However, the evaluation of the first summer period using data recordings with very high time resolution up to 0.5 minute scan-values gave more detailed insight to system operation. These results showed the necessity of a modification of the control strategy in order to take into account that the return temperatures in the district heating network are rather high. This modification was achieved by changing the position of some temperature sensors aiming at earlier system start-up characteristics. Furthermore the temperature differences that determine the switching operations have been varied in order to improve the system operation. As a consequence of these measures the operational time during the day could be improved.

As a conclusion of these experiments it has to be mentioned that despite the considered improvement most problems concerning system control are linked to the very high return temperatures in the district heating network.

In the first two years of collector system operation the control units caused no failures despite the fact that the time difference between switch on and off criteria hasn't been maintained all the time. The collector company solved this problem in May of this year.

In summer 1995 some problems have been encountered that are caused by interference signals in the control units. These faults sometimes lead to wrong temperature values of the sensors that determine the control conditions and cause normally impossible switching operations. As a result of these failures sometimes higher temperatures occur in the collector loops.

B 4.1.4   Collector cover soiling

As mentioned before, one of the most noticeable subjects of the investigations is the increasing soiling of the collector covers. Due to unexpected reduction of collector efficiency values in 1994 in comparison to 1993, it was decided to clean the south collector array in summer 1995.

This work was carried out in the beginning of June. The cleaning of the collector array turned out to be more difficult than expected. First attempts using a high-pressure cleaning machine didn't succeed, but wiping with a sponge in combination with a cleansing agent gave a good result. And by visual inspection, a considerable difference between cleaned and soiled glasses has been recognized.

A first comparative analysis of in-situ measurements of collector array efficiency values in July 1995 indicated the success of the measures. But in order to investigate the effect more in detail, two cover glasses of the west collector array have been exchanged in August 95.

These two cover sheets have been used for a stationary indoor test of a 2.5 m2 collector module using the sun simulator SUSI at the ISFH. The results of this investigations are shown in table 5.

glass cover	soiled	cleaned	new
η_0	0.665	0.73	0.746

Table 5:   Results of stationary indoor test with different glass cover conditions

The difference of the conversation factor between soiled and cleaned glass covers is about 6.5 %-points and even more in comparison to new cover sheets. This indicates a clearly recognizable reduction of the transparency of the glass cover which leads to a reduced energy output of the solar collectors. This effect seems to be rather large in comparison to values stated in the literature.

In our opinion the main reason for the soiling must be the large extent of air pollution that is caused by exhaust emission of the traffic in the center of the town and due to the close vicinity of the cogeneration plant to the central railway-station of Göttigen, were many locomotives are still operated with diesel engines. At the moment it's not yet quite clear how to handle this problem in the future.

B 4.2   Maintenance

Up to now no real maintenance work had to be done by the utility company. In future an Input/Output-controller unit will be installed in the controll-room in order to recognize eventual operational failures.

B 5. Evaluation program

B 5.1   Acquisition system

B 5.1.1   Monitoring program

Within the framework of the scientific and technical investigations and in order to analyze the energetical behaviour of the two systems the ISFH installed a detailed monitoring system in the cogeneration plant in Göttingen.

The monitoring concept contains the relevant meteorological data like solar radiation, which is measured by 4 pyranometers which are installed according to the orientation of the three collector arrays as well as of the solar air collector field, the ambient temperature and the wind speed. Furthermore, all measured data the temperatures and flow rates are recorded in order to investigate the energy output of each collector array. All temperatures are measured by resistance thermometers (Pt 100) which have been selected and calibrated individually.
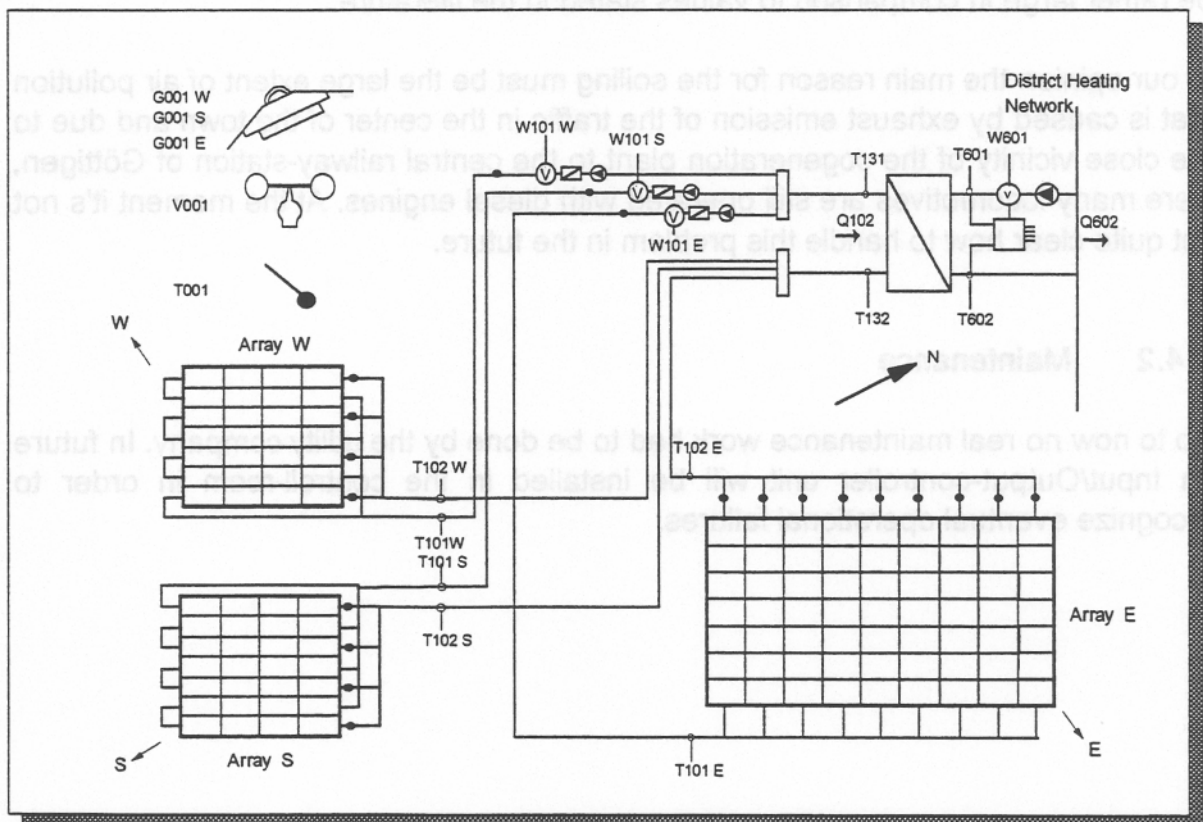
Figure B-10: Key measurement sensors of the flat plate collector system

Figure B-10 indicates the positions of the different sensors installed in the flat plate collector system in Göttingen.

The continuous operation of the monitoring system started in April 1993. Since then the values of 65 sensors are recorded in 10-second-intervals and saved in 5- or 10-minute-mean values on the harddisk. Furthermore some special data can be calculated by the data acquisition program directly in order to perform a quick in-situ investigation of the system.

B 5.1.2   Operation and maintenance

Up to now the data acquisition system works without any major problems. Only the failure of a magnetic flow transmitter caused some problems, causing a data gap for the energetical analysis of the East collector array between May and July 1993. Furthermore two temperature sensors broke down, which are used for control functions and which are not necessary for the energetical investigations.

The measuring program - developed at the ISFH - ensures a continuous operation of the monitoring system. The operation of the PC-based monitoring system is continuous and automatic, only maintenance works have to be done in regular intervals.

It has to be pointed out, that the extreme operating conditions for the measurement and control system hardware are those of an electricity producing power plant building, with high interference voltages and high temperatures inside the building.

These environmental conditions may be demonstrated by the following example:

While changing to the co-generation operating mode in the power plant in September 1994, during start-up of the turbine-generator unit, high voltage peaks had been emitted into the main electricity net, causing damage to each of the fuses of all three magnetic flow transmitters.

B 5.2   Input / Output - diagnosis

The Input/Output-method has been used for the evaluation of thermal solar systems since the end of the 70'ies. It can be described as an intelligent 'Solar-Energy-Heat-Meter' which is capable to calculate the expected daily collector output on the basis of daily Input/Output-regression of a collector array, taking into account the measured daily irradiation and the actual operating temperature of the collector.

Apart from this the Input/Output-method can be used to point out either if the collectors are in good operating conditions or if there is a failure in the monitoring system.

In Autumn 1994 the Input/Output-regression algorithm has been implemented into the data acquisition system in Göttingen. Figure B-11 shows an illustration of the computer display for the analysis of 10 days operation period for the three collector

array. This example demonstrated a verification accuracy of less than 5 % of the average daily collector yield.

 Furthermore it is possible to check the last 60 days of every collector array on the display in order to compare the measured and the I/O-predicted system output.

Routine for the indication of ' Input / Output - Controller ' - Data
Summary

| Available data basis: | | | | 60 days | | |
| Analysis sequence cover the last | | | | 10 days | | |

Array	Start	Stop	Q112.M [kWh/m²d]	Q112.R [kWh/m²d]	Deviation [%]	anal. days
Array 1	21.06.	30.06.	1.396	1.363	2.36	10
Array 2	21.06.	30.06	1.508	1.443	4.31	10
Array 3	21.06.	30.06.	1.605	1.551	3.36	10

Change of analysis length? . . . . Code number !
forward ? . . . . one button ! / back ? . . . . ESC !
Display of all days (Array 1 . . 3) . . . . 1, 2 oder 3 !

Figure B-11: Computer display of the Input/Output system verification

Experiences up to now indicate that the Input/Output-regression methodology facilitates an easy and fast check of both the system operation as well as system performance. As compared to the state of the art of operation check, i.e. visual inspection of the status light of the collector pump, the Input/Output-Controller concept is a great improvement for the local staff as well as for the collector manufacturer.

As the staff of the cogeneration powerplant of the district heating system needs in future continuous information on the operational status of the solar system, a ISFH-I/O-controller will be installed in the control room of the building in 1996.

B 6. Measured performance

In order to analyze the energetical behavior of the solar system, a data acquisition system has been installed in the co-generation plant in Göttingen which operates continuously, scanning 65 sensors in 10 s intervals and storing 5 or 10 minute average values since the begin of April 1993.

Based on this monitoring program, several investigations have been made concerning the following items:
▸ ⬜ collector efficiency based on hourly data,
▸   daily Input / Output - diagram,
      annual and monthly performance,
▸ ⬜ comparison to simulation results.

B 6.1   Collector efficiency based on hourly data

The collector efficiency is the most usual concept to characterize solar collector systems. In order to find out whether the collector modules are In good conditions or not, the comparison of in-situ measurements of collector efficiency to stationary indoor test results provides a good solution.

Figure B-12 shows the indoor test results of a typical solar collector module as installed in the CSHP system in Göttingen, which have been determined with the sun simulator SUSI I at the ISFH. The efficiency curves presented have been measured for different irradiance values from 400 to 1000 W/m2.
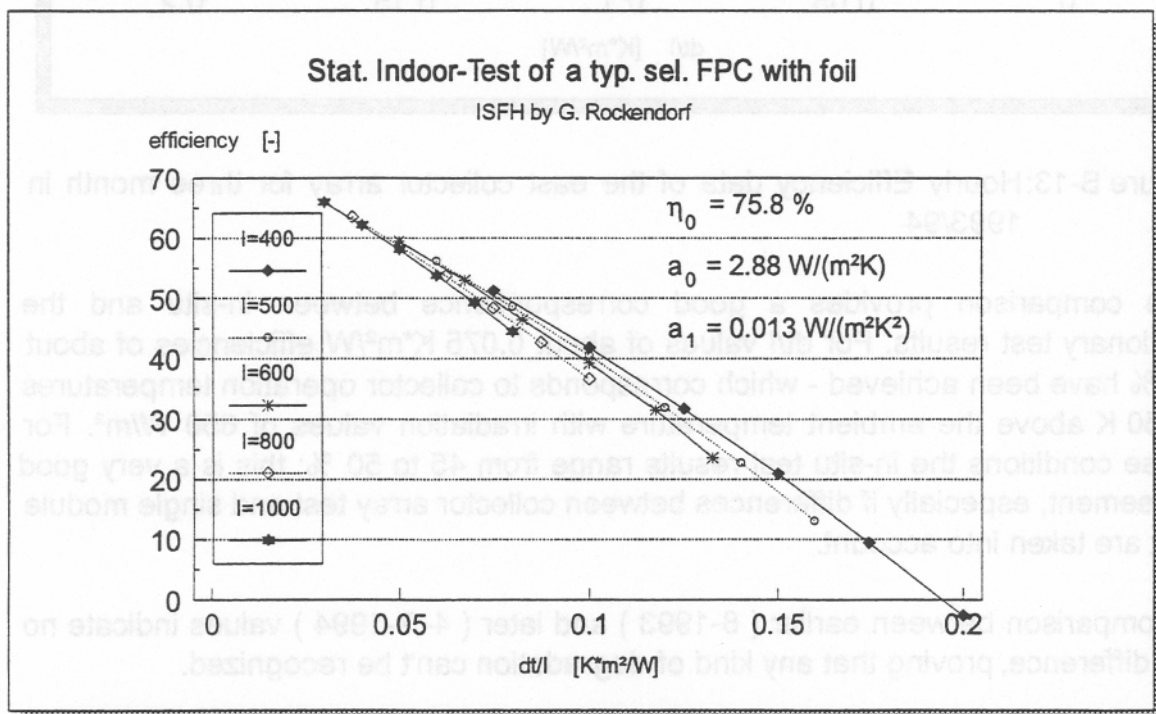
Figure B-12: Stationary indoor test results of a 2.5 m^2 collector module

Figure B-13 indicates hourly in-situ efficiency values of the east collector array from August 1993, April and July 1994. This graph presents only values selected according to the following filter conditions: continuous operation in the actual hour; a^y. irradiance higher than 600 W/m^2; near-normal incidence angle (angular difference to collector normal ± 30 °). Furthermore, a collector capacity correction term has been used to account for dynamic operation conditions of the ay. collector temperature /Vanoli, 1984/.
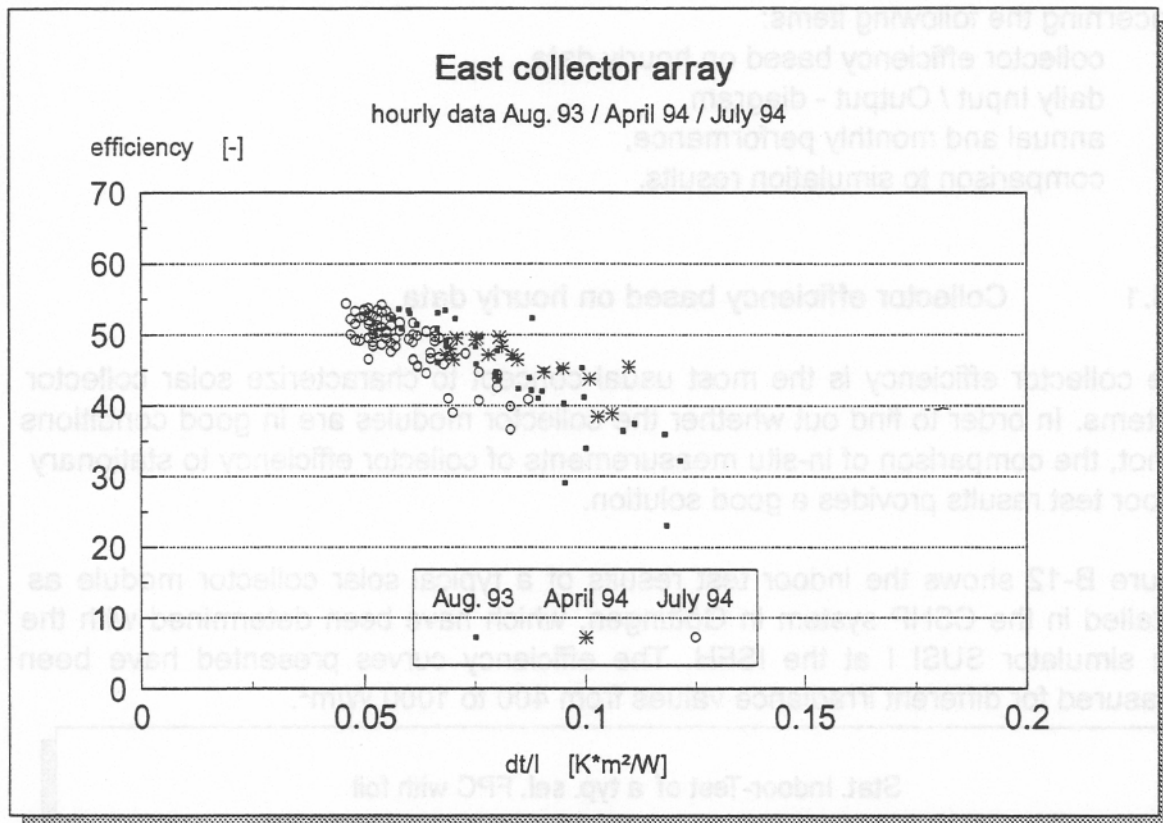
Figure B-13:Hourly Efficiency data of the east collector array for three month in 1993/94

The comparison provides a good correspondence between in-situ and the stationary test results. For dt/l values of about 0.075 K*m²/

50 % have been achieved - which corresponds to collector operation temperatures of 50 K above the ambient temperature with irradiation values of 650 W/m^2. For these conditions the in-situ test results range from 45 to 50 %; this is a very good agreement, especially if differences between collector array test and single module test are taken into account.

A comparison between earlier (8-1993) and later (4-,7-1994) values indicate no big difference, proving that any kind of degradation can't be recognized.

The only change is the shifting of the July '94 efficiencies to lower values of dt/l. On one hand this is caused by the high irradiation during this whole month, on the

other hand it is a result of the lowering the collector temperatures , caused by changes in the district heating network. (cf. Chapter B. 7)
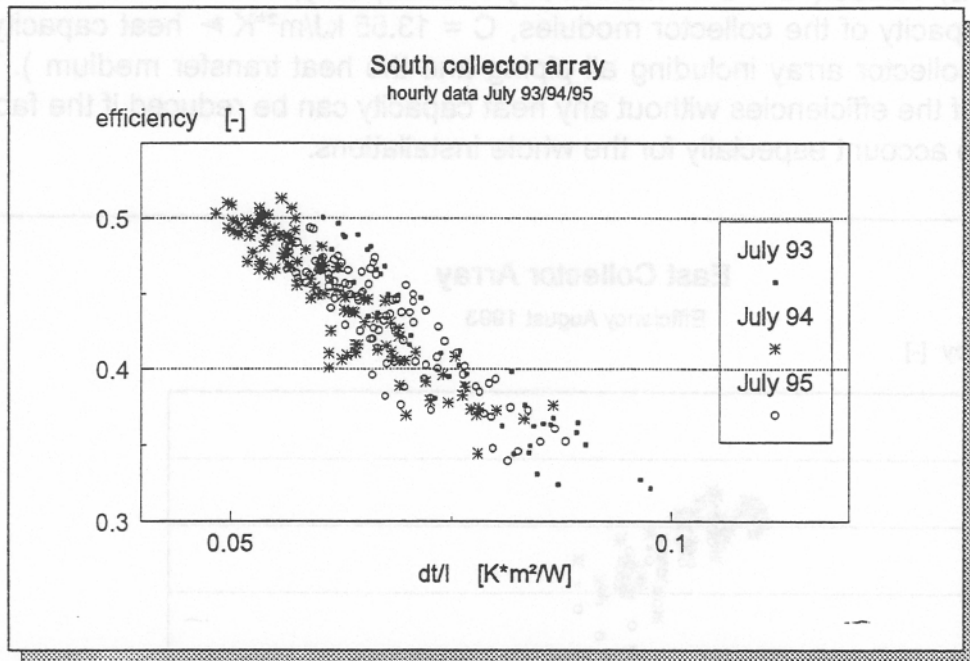
Figure B-14: Hourly efficiency values: south collector array for July in the years 1993/94/95

The influence of the soiled glass cover on the collector array performance is shown in figures 14 and 15. These diagrams indicate that even in July 1995 the efficiency values nearly reach the values of 1993. Only the scattering seems to be a little bit higher.
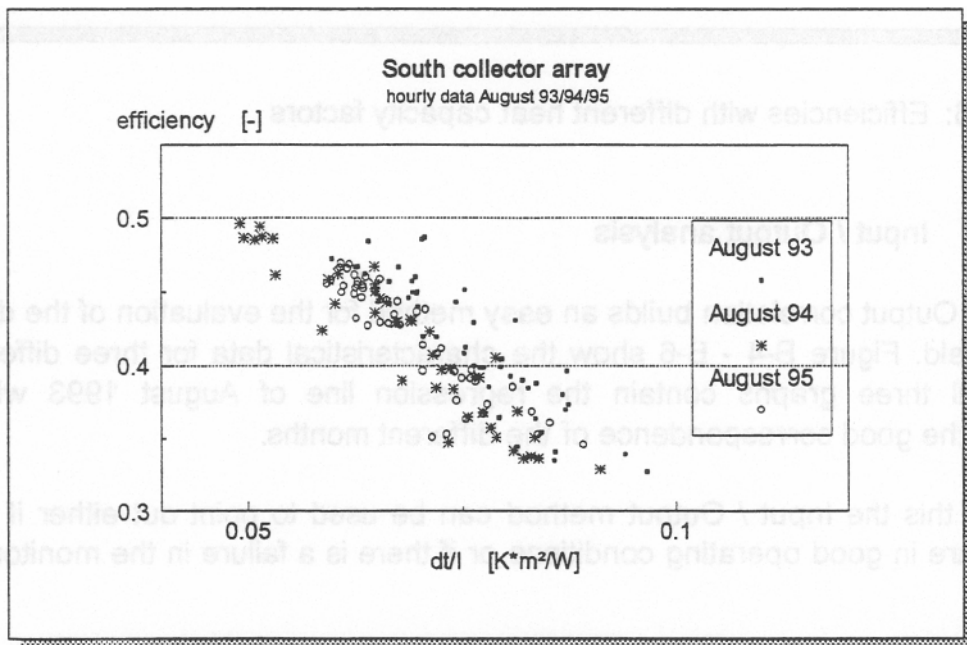
Figure B-15: Hourly efficiency values of the south collector array for August in the years 1993/94/95

To demonstrate the dynamic effects of the real system, figure B-16 shows the efficiencies of the east collector array for August 1993 calculated with different heat capacity values ($C = 0$ ► without any heat capacity, $C = 6.8$ kJ/m^2*K ► only the heat capacity of the collector modules, $C = 13.55$ kJ/m^2*K ► heat capacity of the whole collector array including all piping and the heat transfer medium). The scattering of the efficiencies without any heat capacity can be reduced if the factor is taken into account especially for the whole installations.
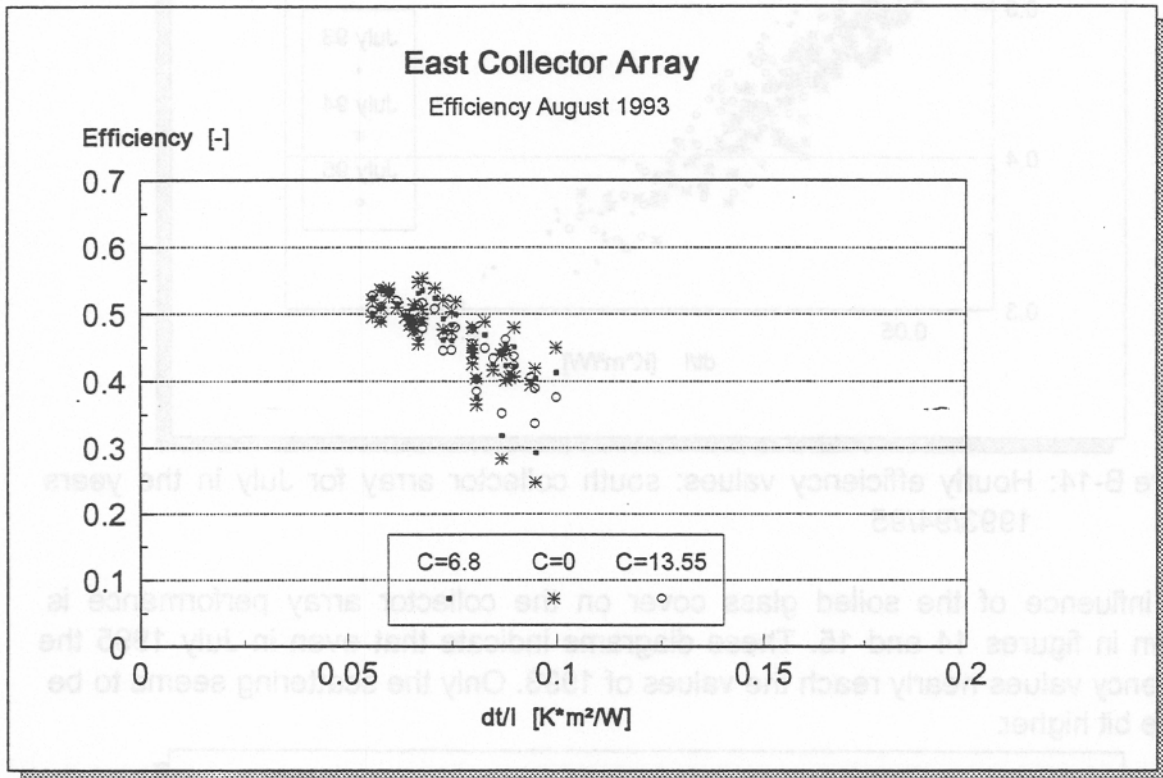
Figure B-16: Efficiencies with different heat capacity factors

B 6.2   Input / Output analysis

The Input / Output correlation builds an easy method for the evaluation of the daily collector yield. Figure B-4 - B-6 show the characteristical data for three different months. All three graphs contain the regression line of August 1993 which expresses the good correspondence of the different months.

Apart from this the Input / Output method can be used to point out either if the collectors are in good operating conditions or if there is a failure in the monitoring system.

In Autumn 1994 the correlation has been implemented into the monitoring program in Göttingen. First investigations proved, that it is possible to verify the predicted daily collector output within an accuracy better than 10 %.
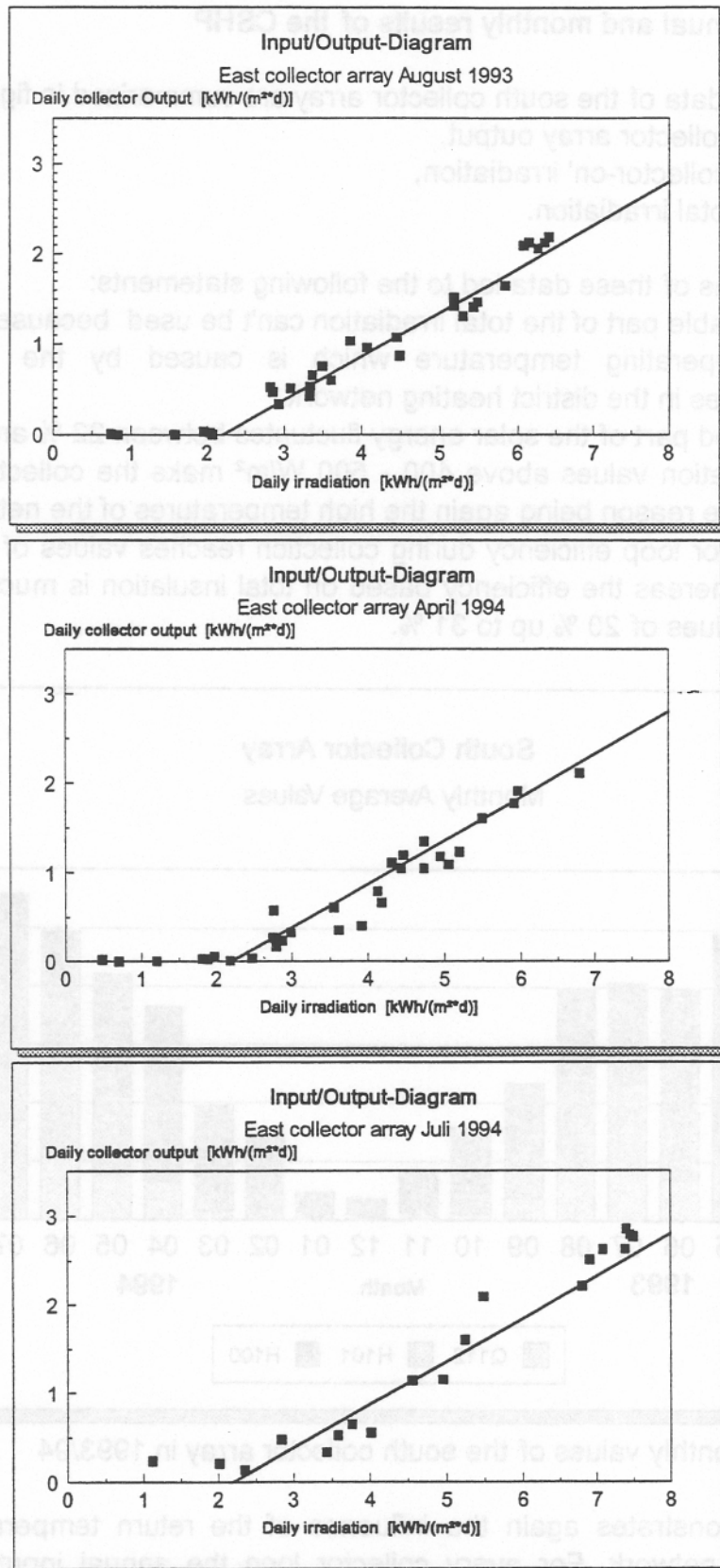
Figure B-17 - B-19: Input / Output correlation for three different months of the east collector array

B 6.3　　　　　Annual and monthly results of the CSHP

Typical monthly data of the south collector array are summarized in figure B-20:
- Q 112 $\overset{\wedge}{=}$ collector array output,
- H 101 $\overset{\wedge}{=}$ 'collector-on' irradiation,
- H 100 $\overset{\wedge}{=}$ total irradiation.

The investigations of these data led to the following statements:
► A considerable part of the total irradiation can't be used because of the high collector operating temperature which is caused by the high return temperatures in the district heating network.
   ▸ The un-used part of the solar energy fluctuates between 22 % and 50 %.
► Only irradiation values above 400 - 500 W/m^2 make the collector operating possible, the reason being again the high temperatures of the network
   ▸ The collector loop efficiency during collection reaches values of about 37% to 40 % whereas the efficiency based on total insulation is much lower with monthly values of 20 % up to 31 %.
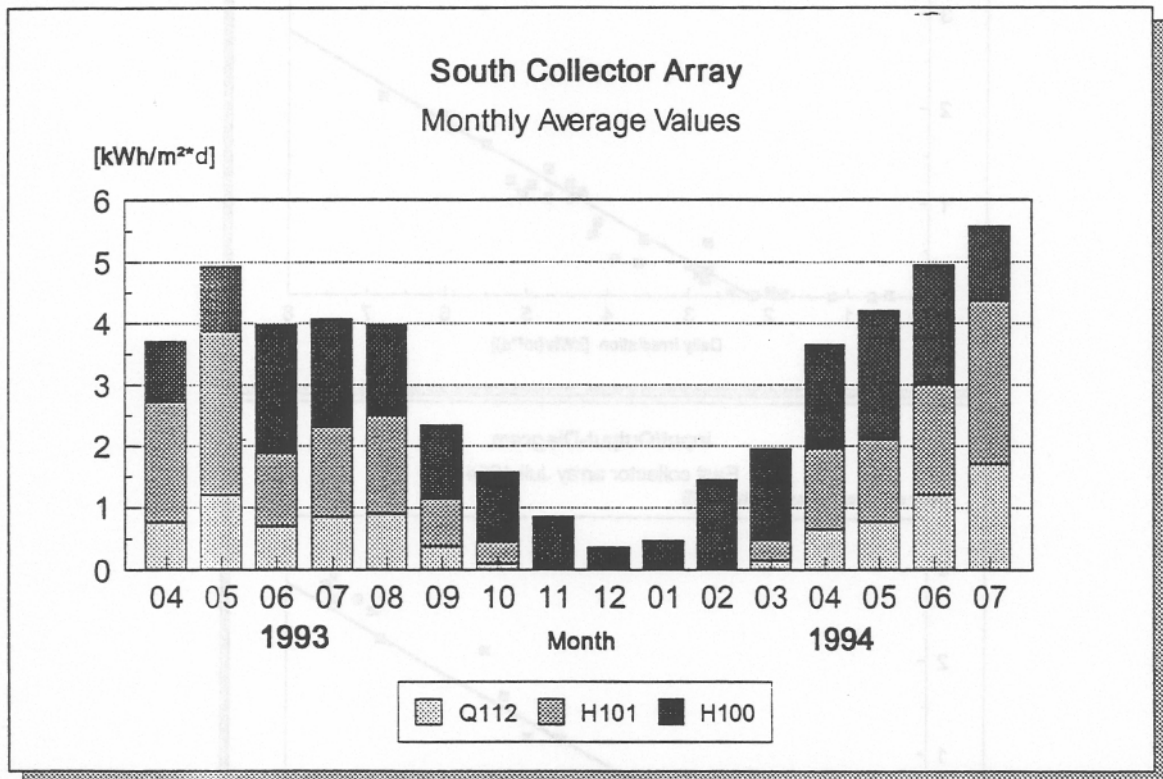
Figure B-20: Monthly values of the south collector array in 1993/94

Table B-6 demonstrates again the influence of the return temperature of the district heating network. For every collector loop the annual input, output and efficiency values are collected. In comparison to the real system, the simulated efficiencies are mentioned, too. These efficiencies indicate the importance of lowering the return temperature in the network.

array	irradiation [kWh]	collector output [kWh]	measured efficiency [%], $t_{RL} \sim 72°C$	simulated efficiency [%], $t_{RL} = 40°C$	reduced performance [%]
east	370.797	73.788	20	39	48,7
south	134.718	22.494	17	39	56,4
west	113.167	14.388	13	33,5	61,2
sum	618.682	110.670	18	38,2	

Table B-6:   Annual results of the first period April 93 - March 94

This table shows additionally the percentage of reduced performance due to high operating temperature. The collector yield is reduced by 48,7 % for the east array, and by more than 60 % for the west array. It has to be concluded, that the suitability of solar roofs depends also on the operating temperature.

Array	T001	H100	Q112	N001	N110	N111	E103	DL100	T601
	[°C]	[kWh/m²a]	[kWh/m²a]	[%]	[%]	[%]	[%]	[h]	[°C]
1. Measuring period Sept. 1993 - Aug. 1994									
East	9,88	950,45	195,09	55,06	20,53	37,28	3,78	839,5	68,73
South	9,88	953,91	176,12	48,42	18,28	37,76	3,71	725,6	68,45
West	9,88	857,86	118,46	36,83	13,75	37,34	4,23	539,3	68,89
2. Measuring period Sept. 1994 - Aug. 1995									
East	10,48	969,35	189,72	58,55	19,57	33,43	4,28	922,9	69,84
South	10,48	970,03	167,25	46,94	17,07	36,37	3,79	704	70,31
West	10,48	870,95	111,12	37,67	12,71	33,73	4,82	575,8	70,98

T001   Ambient temperature   H100   Irradiance in the collector plane
Q112   Solar energy collected   N001   Ratio irradiance to irrad. on operation
N110   Efficiency based on irradiance   E103   Ratio pump energy to Q112
N111   Efficiency based on collector on irradiance
DL100 Operating hours   T601   Return temperature (cf. footnote)[1]

Table B-7: Comparison of two annual measuring periods

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[1]   T 601 as reference DH-network Temperature is averaged during the time of collector, operation, causing slight daily variations over the measurement period

In order to compare annual values of the collector array performance, two periods between September and August in the years 1993 to 1995 have been analyzed. Table B-7 contains the typical data for these periods.

The performance values of the second measuring period are lower than in the first period. This is caused on one hand by a little bit higher return temperatures in the distribution network and on the other hand by the soiled glass covers.

B 6.4   Comparison to simulation results

Figure 21 shows the results of simulation with the ISFH and TRNSYS programs in comparison to the measured efficiencies as a function of the return temperature of the district heating network.
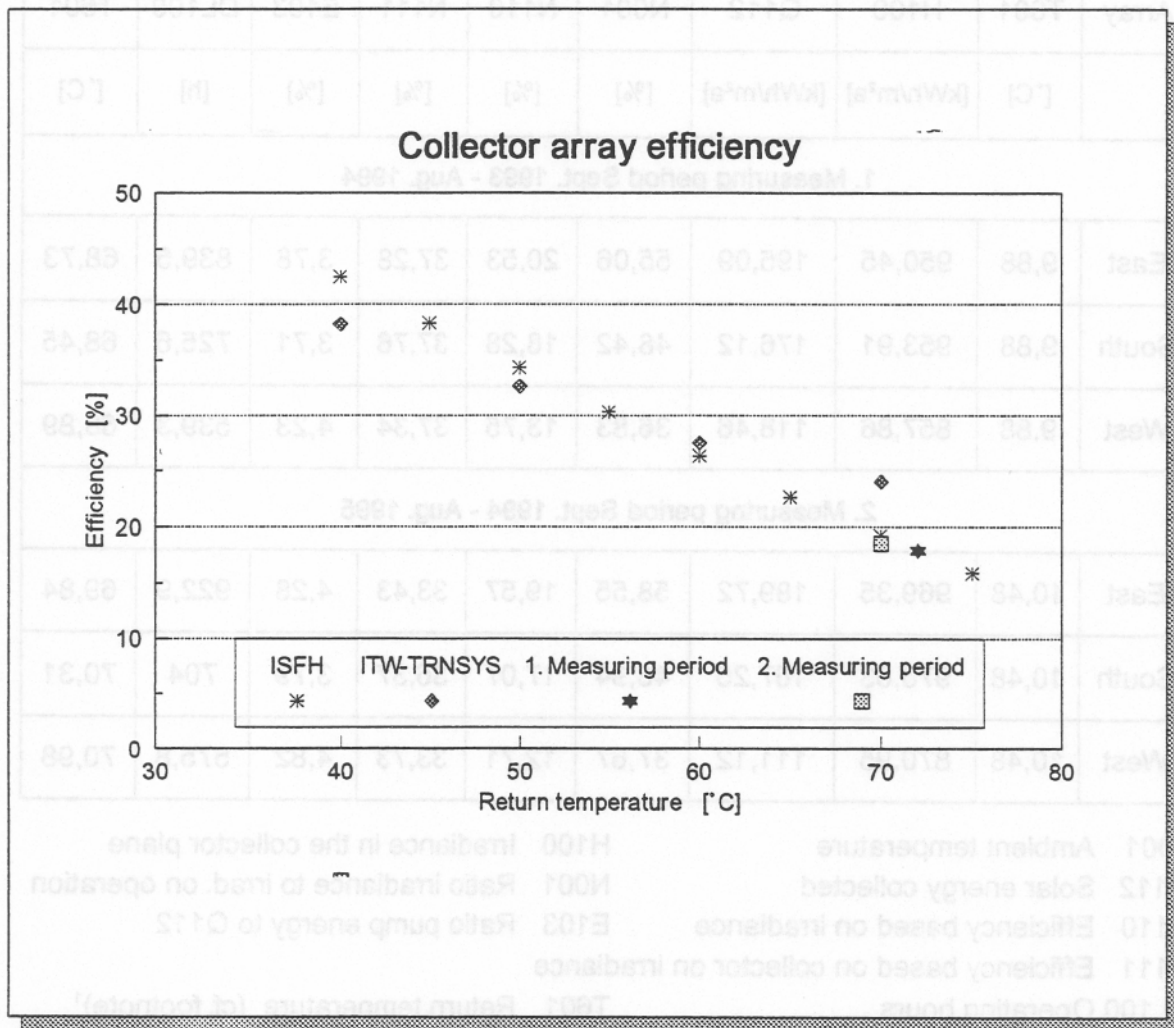
Figure 21: Results of simulations with ISFH and TRNSYS and measured data

The results of the simulation programs are nearly the same. Efficiency values of about 40 % can be reached if the return temperature is about 40 °C. Also the agreement between the measured and the simulated performance is very good, proving that the simulation programs are now precise design tools.

This graph leads to the following conclusions:

▸ again the reliability of the used simulation programs can be noticed,

▸ the measured collector efficiency parameters used in the simulation are correct

▸ the return temperatures in the district heating network are the reason for the difference of about 50 % between simulated and real solar energy output.

B 7. The district heating network

The previous chapters of this report have demonstrated, that the observed 50 percent performance deficit as compared to the projected values is not caused by solar technology, but by the too high return temperatures of the district heating network.

In order to find solutions, the investigations were concentrated on the conventional heating systems as well as on the users substations. This part of the system analysis gives a short overview about the work done in this field.

B 7.1   District heating network return temperature

First pre-studies for the Göttingen project were made on the condition that only a new, modern part of the whole district heating network, that operates with lower temperatures, should be connected to the solar system. Because of the unknown daily load profile in summer, the local utility could not guarantee, that the return flow in this small network would be big enough to take up all available solar energy.

These facts led to the decision to connect the solar system to the main district heating network. Secondly, the local utility has committed itself to manage a lowering of the return temperature down to 40 °C and has agreed, that this action was absolutely necessary, because this concept offers several advantages:

> reduction of network heat-losses,
> increased electric production,
> high solar system efficiency.

During the installation work of the two collector systems first test were made to lower the return temperature in the distribution network by changing the operational mode in the cogeneration plant. It has to be mentioned that until 1991 the Stadtwerke Göttingen AG delivered heat to their customers on a very high temperature level with supply temperatures of about 130 °C and even higher and return temperature of about 110 °C. This was partly caused by some special consumers in the network who operated steam heating system or needed steam for cooking like for example the university kitchen.

Until the end of 1991, all steam systems had been put out of operation. This facilitated work in the powerplant to reach return temperatures of about 90 °C in the network. The next step in lowering the temperature level was the change from fixed to variable supply temperature depending on the ambient temperature. This modification in the operational mode again produced a drop in the return temperature of nearly 20 K.

Figure B-22 shows the measured development of the supply and the return temperature in the distribution network in the town of Gottingen during the three years project period. The temperature profile during the considered period shows the progress in lowering the return temperature by the different measures, but the difference to the values of about 40 °C still is too big.
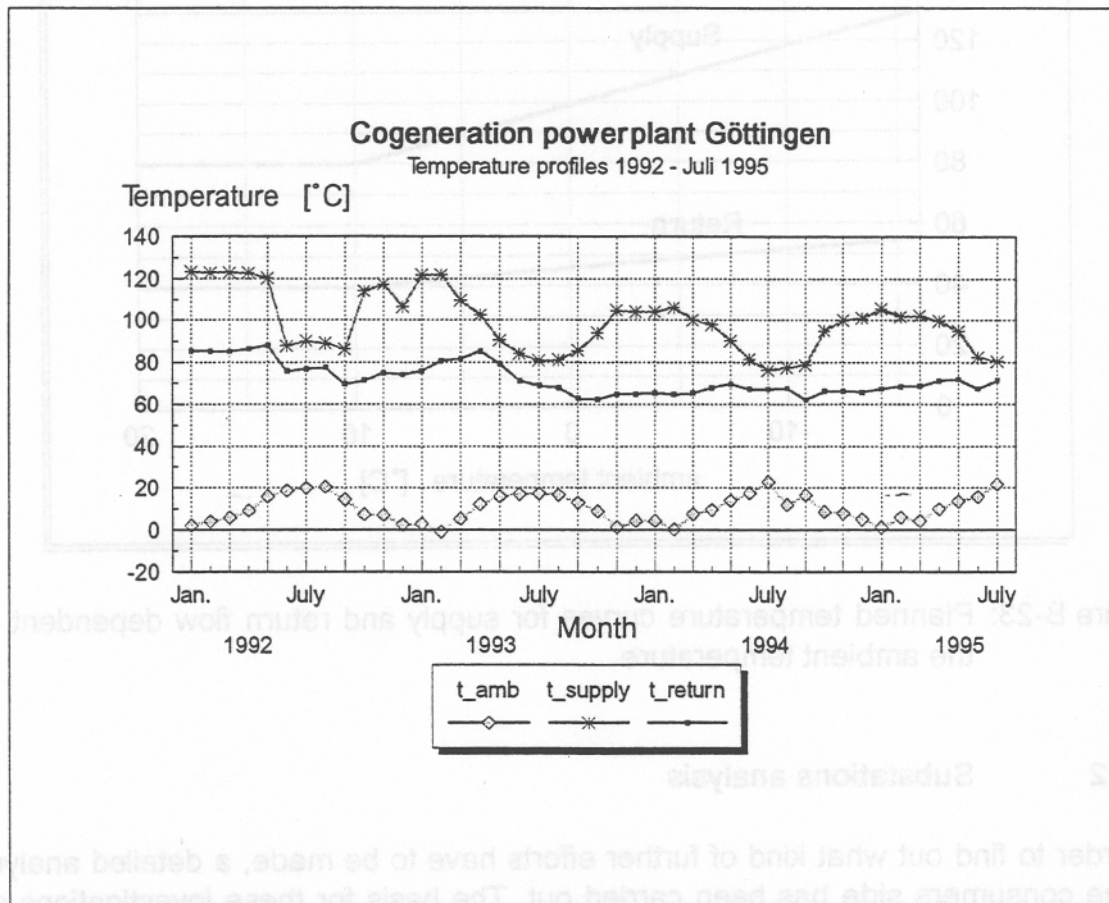
Figure B-22: Temperature curves of supply and return flow in the Göttingen district heating network

The planned temperature mode for supply and return temperatures, that Stadtwerke Göttingen AG want to operate in future is shown in figure B-23.
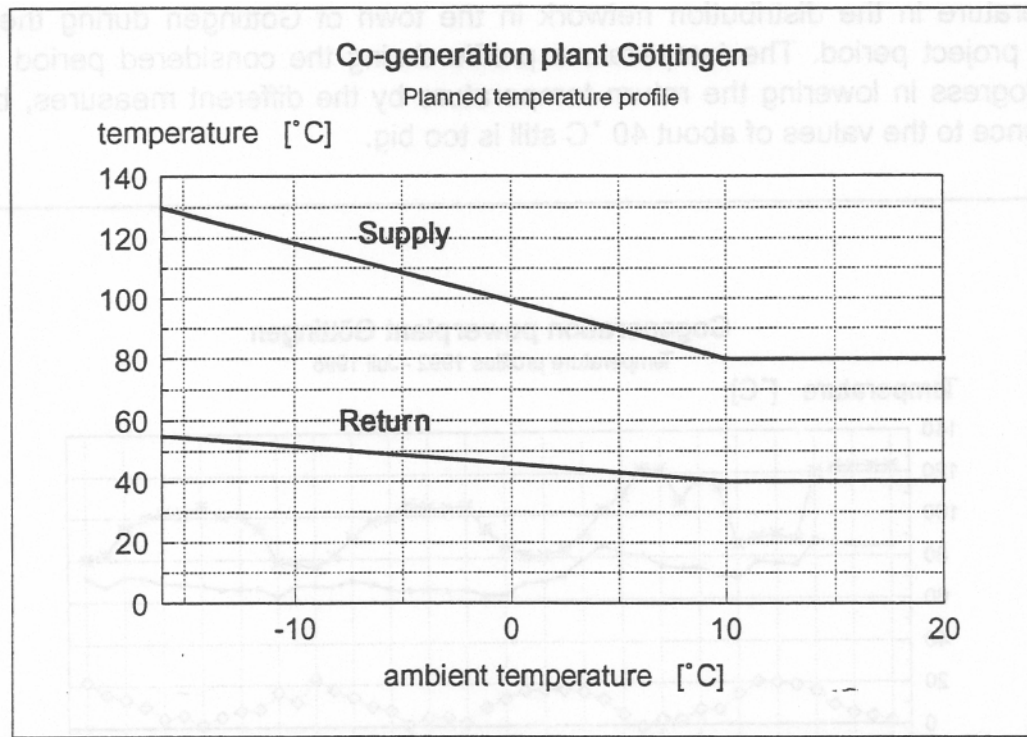
Figure B-23: Planned temperature curves for supply and return flow dependent on the ambient temperature

B 7.2   Substations analysis

In order to find out what kind of further efforts have to be made, a detailed analysis of the consumers side has been carried out. The basis for these investigations are monthly reports of the heat consumption, flow rate and temperature difference between supply and return of every substation in the district heating network.

A first analysis of this substations showed, that a rather big number of stations operate at temperature difference levels lower than 10 K, some stations even lower than 5 K. The next step was the development of a new methodology, to select those substations who are preventing most the low temperature level of the return flow.

In order to perform this selection, a new type of substation-energy-share histogram presented in Figures B-24 and B-25 has been developped: The vertical line gives the cumulated share of heat supply classified by the delta T category as a percentage value of the whole network load, the horizontal line shows a classification of the substation delta-T's in 5 K steps. Thus, the larger the load-share of a given substation and the smaller its delta-T-value, the stronger is its negative impact on high return flow temperatures.

As an example, Figure B-24 shows such a substation-energy-share histogram for the Gottingen district heating network, the figures inside the bars designate the numbers of the different consumers stations. The actual situation presented in Figure B-24 for June 1993 is characterized by a supply temperature of 84 °C, and an average delta-T of the whole network of 12.8 K.
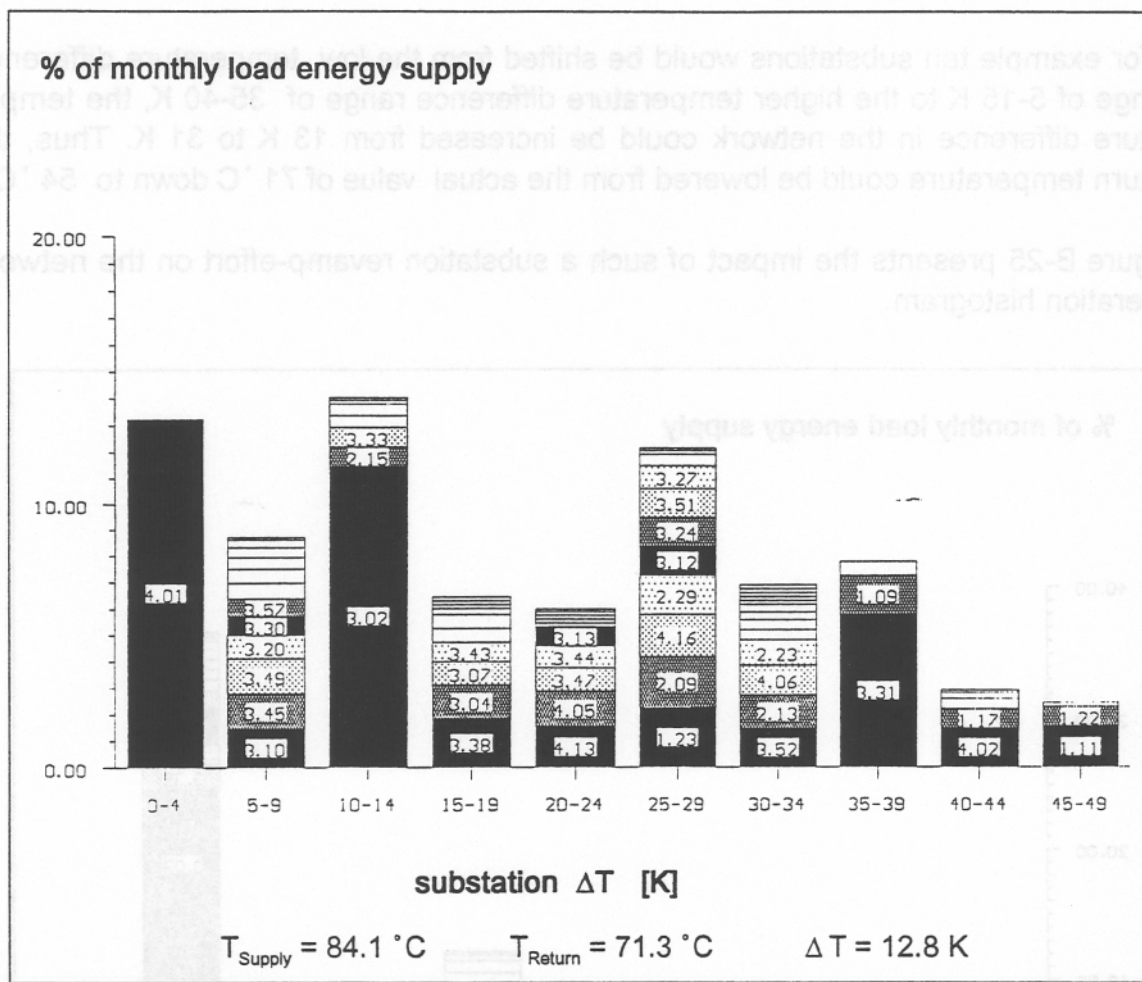
Figure B-24: Substation-energy-share histogram for the Göttingen district heating network for June 1993

With the use of this graph it was possible to select those substations, which are characterized by a high contribution to the total load together with a high substation volume flow rate and hence a small delta-T, thus creating the most problems in the network.

In order to analyse the impact of renovation of a series of individual substations to the total network, a "mixing calculation" has been carried out to determine the average return flow temperature of all network substations. This calculation has been based on the following assumptions:

- bigger heat-exchangers and adapted controllers will increase the substation delta to values of 40 K.
- the substation flow rate will be reduced by the same proportion as the delta-T increase.
- the total network flow rate will be corrected as well.
- the supply temperature is not changed.

If for example ten substations would be shifted from the low temperature difference range of 5-15 K to the higher temperature difference range of 35-40 K, the temperature difference in the network could be increased from 13 K to 31 K. Thus, the return temperature could be lowered from the actual value of 71 °C down to 54 °C.

Figure B-25 presents the impact of such a substation revamp-effort on the network operation histogram.
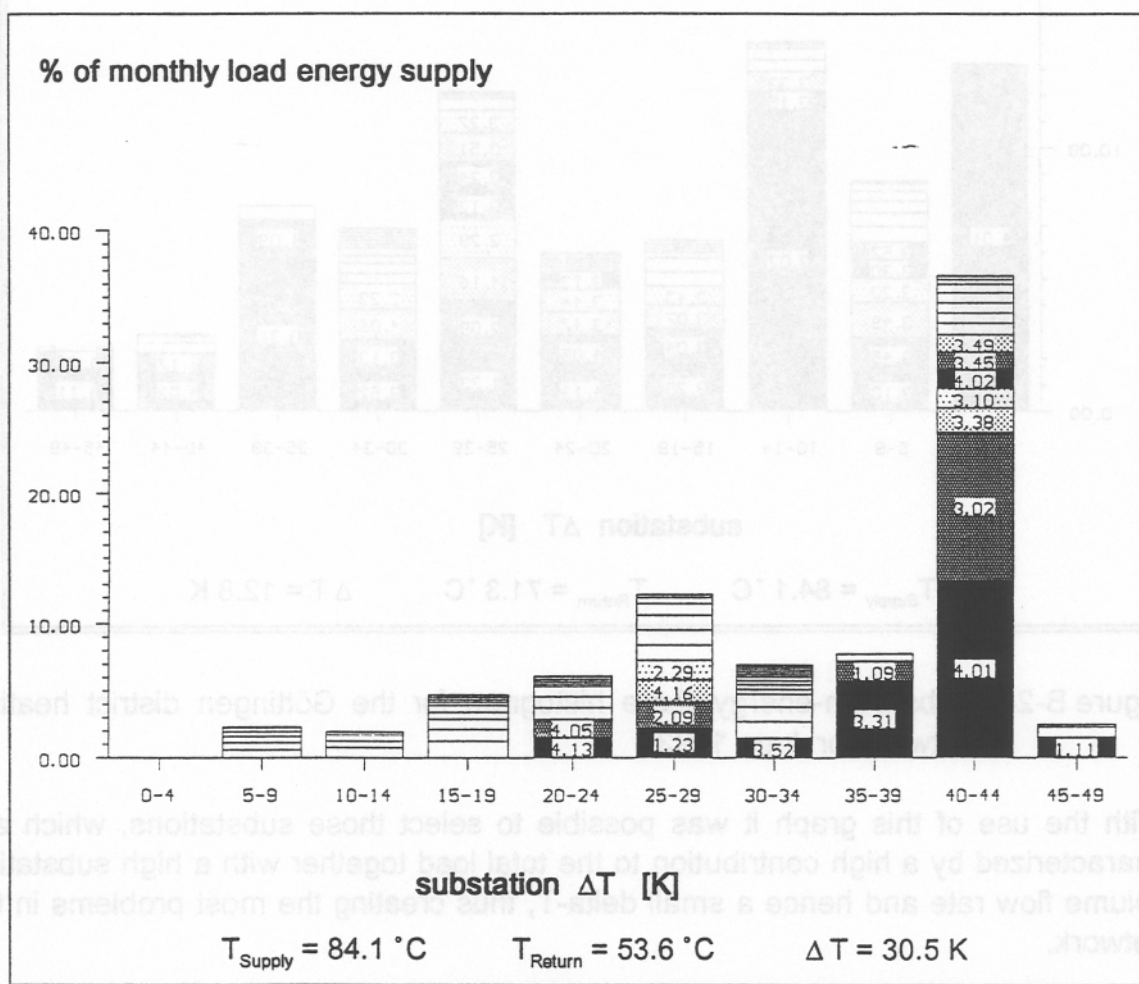
Figure B-25: Substation-energy-share histogram for the Göttingen district heating network with 10 substations revamped to 40 K delta-T

The very important conclusion of these investigations is, that not the whole network has to be changed, but only a few special substations, that cause the biggest problems. This seems to be a good argument for the operator of the system to keep doing its efforts.

B 7.3   New concepts for the district heating optimization

In summer and autumn 1995 new investigations have been carried out to analyze the potential for the lowering of the return temperatures. On one side, seven selected substations have been measured individually during one week and on the other side, the systems in the substations have been analyzed and documented. Technical modifications were planned and their investment calculated. Finally the ISFH developed in cooperation with a German engineering company a comprising concept for the whole DH network based on optimizations concerning the domestic hot water systems.

B 7.3.1   Measurements

Table B-8 presents typical weekly values of the seven substations that have been measured using a mobile monitoring system. The values indicate, that essentially two stations operate under very bad conditions and that virtually all substations dispose of a certain potential for lower return temperatures.

Substation	volume flow rate [m³]	heat demand [MWh]	temperature difference [°C]
Gothaer Versicherung	267	6,6	21,2
Dt. Bundespost	1.333	1,3	0,8
Ritterplan	221	2,4	9,3
Gebhards Hotel	85	2,9	29,2
HNO-Klinik	226	6,5	24,7
Karstadt	204	4,5	18,9
ARES Vermögens-verwaltung	595	1,8	2,6

Table B-8: Measured weekly data of seven selected substations in July/August 1995

It has to be mentioned that during this measuring period from the beginning of July to the end of August the ambient temperature in Göttingen was very high and reached values of about 30 °C and even more. Thus there was no demand for space heating and therefore the measured performance of the consumer substations indicate only the domestic hot water systems.

In order to figure out what problems may occur in these substations, the system of Dt. Bundespost will be analyzed in more detail. Both the measured values as well as the on-site **survey of the client's** installations indicate that the main problem in the station is caused by a wrong adjustment of the control unit. Figure B-26 shows a scheme of the installation in the substation.

Figure B-26:

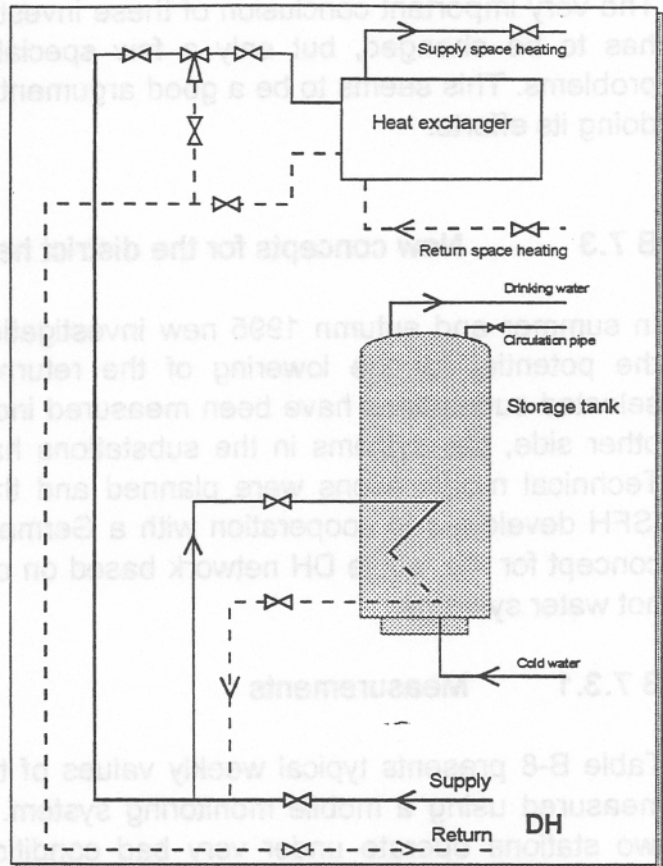Scheme of the Dt. Bundespost

substation **with a storage** domestic hot water system
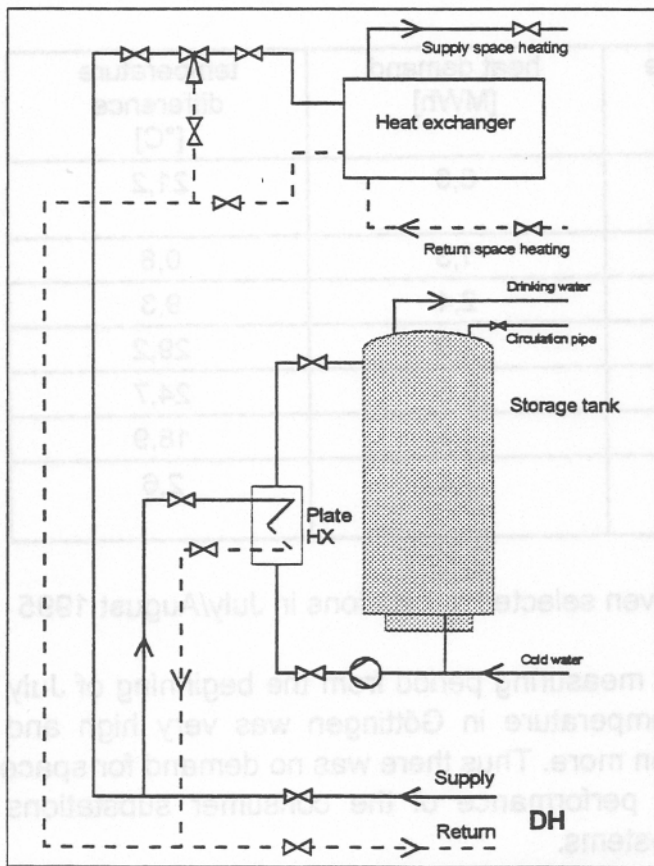
Figure B-27:

  Scheme of the same sub- station with integrated storage charging system using an external plate heat exchanger

The optimization concept of this substation includes two main measures:

> ► at first, the reduction of the secondary nominal supply temperature from 8C) °C down to 60 °C in the summer month;

► in the second place, the modification of the storage DHW system with a totally mixed water storage tank into a storage charging system with a stratified temperature profile using an external plate heat exchanger loop.

Figure B-27 indicates the adjustments to this DHW system which may be a general solution for most of the substations in the DH network.

The cost calculations for the measures in this particular station indicate an investment of about 10.000,- DM. Concerning the other analyzed substations the costs for the proposed optimizations range between 7.000,- DM and 17.000,- DM, depending on the size of the station and it's operational behaviour.

B 7.3.2   Comprehensive optimization concept

Based on the investigations of the seven selected substations a comprehensive optimization concept has been carried out, including both different technical measures to lower the DH return temperatures as well as cost calculations for the optimization of all substations.

The technical concept can be divided in two parts: at first several measures to lower the return temperatures only in the summer month by optimizations of the drinking water systems, and secondly on-going activities including the space heating systems to reach lower return temperatures in winter and in the transitional periods.

The concept for the summer months consists of different design variations for the integration of external plate heat exchangers into the domestic hot water systems as for example a pre-heater that may be fed from the primary or the secondary return flow and an auxiliary heater that should be connected to the primary supply flow. The most promising solution builds a storage charging system which is capable of providing return temperatures about 5 - 10 K above the cold water temperature (see Figure B-27).

In addition, an optimization of the control units in every station facilitates an easy and fast opportunity to reach first improvements in the operational behaviour of the systems.

A more comprehensive concept for the whole network includes the adjustment of the space heating systems, too. Therefore, different steps in the analysis of the consumers installations are necessary:

► at first, a comprising check of the heating system including the size of the radiators in every room has to be carried out (investigations in German DH networks figured out that most of the installed radiators are oversized, especially, if other energy-saving measures may be combined with that action);

► secondly, a hydraulic adjustment of the heating systems depending on the size of the radiators is necessary in order to ensure an optimal temperature drop in the systems (therefore it's unavoidable to use thermostatic superfine regulating valves);

third, the control system and the domestic hot water system have to be optimized as mentioned before;

► last but not least, the nominal primary flow rate has to be adjusted according to the realized measures in order to reduce the nominal heat transfer value (this ensures the costumer to reach a lower heat price).

For the time being, the optimization concept that has been‾ proposed to the Stadtwerke Göttingen AG includes only a new design of the domestic hot water systems of all substations in order to limit the investment costs. This concept ensures lower return temperatures in the network mostly in the summer months.

Based on the cost calculations for the seven analyzed substations the transfer on all consumers systems delivers investment costs of 850.000,- DM, which means on the average nearly 6.100,- DM for one single substation. This seems to be very cheap in order to improve on one side the operational behaviour of the stations and on the other side the solar energy output.

The completion of the cost/performance analysis for the whole optimization measure is still in progress. A final decision will be taken in the middle of 1996.

B 7.4   Conclusions

Concerning the lowering of the return temperatures, the main conclusions in the Göttingen project are:

•   Besides the lowering of the return temperature during the first period of the project reached by adjustments in the operational mode of the cogeneration plant, no further temperature drop has been achieved.

•   A comprehensive concept for the optimization of all substations based on new designs of the hot water systems results in investment costs of about 850.000,- DM.

- The most promising measure concerning the' hot water systems builds a storage charging system which enables low return temperatures.

- Revamp concepts including the hot water and the heating system require first a complete on-site survey of all costumers installations and a hydraulic adjustment; the installation of thermostatic superfine regulating valves is unavoidable.

- A good cooperation between the customer and the utility is crucial, especially if legal aspects are taken into account.

- Continuous checks and adjustments of the consumers installations on a regular basis are essential to maintain a low DH return temperature.

- Regular inspections of the substations are necessary to prove and verify contractual guaranteed values.

- Updates of documentations concerning the costumers installations are very helpful.

- Substations equipped with control units enabling data transmission ensure a quick check of the operational behaviour of the systems.

B 8. Conclusions and outlook

The Central Solar Heating Project Göttingen, which builds the first project in Germany to connect a large solar system to an existing District Heating network, reveals several aspects concerning the technique of large collector arrays as well as the operational behaviour in the conventional part of the system. The investment of this project had been funded on a 50 % basis by the Stadtwerke Göttingen and the Ministry of Economy of Niedersachsen (Lower Saxony). The accompanying scientfic research and demonstration project has bee funded totally by the Federal Ministry for Research and Technology (BMBF).

As a general result, several steps on the learning curve of this system combination have been achieved by this project.

The energetical analysis of the collector arrays indicates, that under the given operating conditions, solar technology has performed according to its capabilities, without significant degradation and to a high degree of reliability. During three years of operation only a very small number of failures occured and the most noticeable thing is a certain extent of soiling on the cover glasses of the collector modules.

The temperature based control units of the three collector arrays performed as expected, apart from some problems that occured due to the very high return temperatures in the DH network. Furthermore no real maintenance work had to be done by the utility company.

The integration of the Input/Output-correlation into the monitoring system proved a possible prediction of the daily collector output within an accuracy better than 10 %. Apart from this, this method can be used to point out either if the collectors are in good operating conditions or if there is a failure in the monitoring system.

The comparison between the results of the simulation performed by the ISFH- and TRNSYS - programs and the measured performance proves the reliability of these models and indicates that these programs are very precise design tools, nowadays.

The major problem in the Göttingen solar district heating project is caused by the high DH return temperature. During the initial period of the project, changes in the operating mode of the co-generation plant resulted in a substantial temperature reduction, starting from 90 °C at project start down to 70 °C now. The report presented indicates, that for several reasons it was not yet possible to reach lower values until today.

Some attempts were made by the installation of new controllers at several substations acting both on the return temperature as well as on the flow rate, depending on the actual load and supply temperatures. But for several reasons, this measure was not very successful.

In spring of 1995, a big investigation program has been set up to estimate the possibilities for lowering the return temperatures in the DH network. This program included measurements at several substations as well as surveys of the consumer installations. Based on these investigations, an extensive modernization concept for the whole DH network has been elaborated in co-operation with engineering companies of the classical district heating domain.

The main conclusion of these investigations reveals that there is a huge potential for a substantial reduction of the network return temperature. The optimization study indicates, that a revamp of the hot water systems in all substations result in an investment costs of about 850.000,- DM. With this concept, which essentially includes the revamps of the systems by an installation of storage charging systems, it will be possible to lower the DH return temperature to values of nearly 45 °C in the summer months.

More general concepts are based on optimizations including the space heating systems, which will reduce the temperature over the whole year but they cause higher investments than the proposed concept. In this case, it would be possible to find different ways to divide the costs between the consumers and the local utility and which results in lower energy prices for the clients.

Both proposals to lower the network temperature are characterized by improvements both due to the efficiency increase of the solar system as well as due to a considerable reduction of network losses over the whole year.

In general, it has to be stated that in any case, the lowering of the DH network temperatures is advantageous for all participants. Furthermore it's some kind of deplorable that the integration of a solar system reveals a number of problems that occur in the conventional energy system.

Particularly for the Göttingen project we are hopeful that the proposed concept will be put into action and that in future better operating conditions will lead to an improvement both of the solar system as well as of the conventional part of the DH network.

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APPENDIX C: PROJECT DESCRIPTION OF THE LISSE BULB DRYING PLANT (THE NETHERLANDS)

The Lisse Bulb drying plant with diurnal used seasonal storage

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Solar Heating & Cooling Programme

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C. PROJECT DESCRIPTION OF THE LISSE BULB DRYING PLANT

C.1   SUMMARY

Beginning 1990 a project on bulb drying in Lisse was initiated. This initiative was worked out towards a large (EU) demonstration project, also to be used as research project within lEA SH&C programme Task 14. The project started with a feasibility study. The heat demand is characteristic for these type of processes. After harvest, the bulbs are dried in order to prevent for infections. The drying takes place in the summer with heated ambient air. Next, the bulbs undergo an artificial autumn and winter cycle through conditioning. Herewith the time of flowering of the bulbs is established. Although the heat demand is high, the temperature levels are low. The future yearly heating load will be about 5.7 TJ. A global comparison of the price/performance ratios of several systems was carried out. A fluid based system with a seasonal storage, which is charged/discharged twice a year, turned out to be considerably more cost-effective than alternatives and is more innovative and interesting. For those reasons the project fitted in the lEA Task 14 framework.
The construction work for the project started beginning 1993. Due to the special requirements for the storage, as well as the specific soil conditions and groundwater level, the storage didn't allow for a standard construction. Among others the 1000 m^3 storage had to meet the following requirements: temperature resistance 25°- 80° C, the top of the storage to be used as factory-floor, durable insulation on all sites of the store, no water leakages in-or out the storage. Special attention for the construction was caused by the fact that the groundwater level will vary between 0.6 and 1.0 m^1 below ground level. This condition will make the storage a floating vessel during construction and/or maintenance situations, with an actual danger of rising.Apart from this, the requirement that the top of the storage should be used as factory floor a foundation with concrete pilings through the storage tank was unavoidable.
The construction of the storage turned out to be the most critical and difficult element of the system. Finally the storage tank was constructed with polystyrene on the top and the bottom. The bottom of the store is ballasted with concrete to avoid floating of the polystyrene insulation. The store walls are insulated with foamglass with a special coating on top to prevent etching.
In the end of 1994 the system was finished and came into operation. The first monitoring year was 1995. Results show a much lower energy demand of the drying plant then predicted. This results in 1995 in a solar contribution of 64% to the drying wall. The total system efficiency however, is only 15%. The store efficiency is only 47% whereas 95% was expected from the design study. The heat loss coefficient of the store per m^2 surface is about 0.6 $W/(m^2.K)$ where the design value was about 0.35 $W/(m^2.K)$. Due to the long project development time the original system and process criteria have changed. This causes an other use of the system as originally foreseen. For instance the water to air heaters in the drying wall probably have a lower heat transfer coefficient as designed. During the first months of 1996 further analysis will take place, in order to further optimize the thermal performance of this system.

C.2   PROJECT INITIATION

The company "Dames en Werkhoven" is situated in Lisse, in one of the main Dutch areas of flower bulb production. Beginning 1990 the owner of the plant showed interest in solar energy application as future energy source for his process. During the following years this interest is worked out towards a large demonstration project. At this moment, the system has been working for about 1 year. The project started with a feasibility study. As a result the outline of the system was defined. An application for funding in the framework of the EU Thermie [5] programme was put forward end 1991. Approval of the project with a 5% budget reduction was received in 1992. End 1992 the contract was made and realisation of the project could start. During the project the construction of the storage tank caused problems and delayed the project. End 1994 the system
came into operation and since that time monitoring takes place.
During Task 14 activities the Lisse system was developed, discussed within the Task, realised, commissioned and monitored for about 1 year (1995).

C.3   FEASIBILITY STUDY

C.3.1 Introduction

The company " Dames and Werkhoven" consists of a number of small and large buildings. The rooms are used for heating, cooling and storing of the bulbs in the various conditioning stages, as well as for office activities. The situation and dimensions of the most important rooms are A and B, presented in fig. C.1.
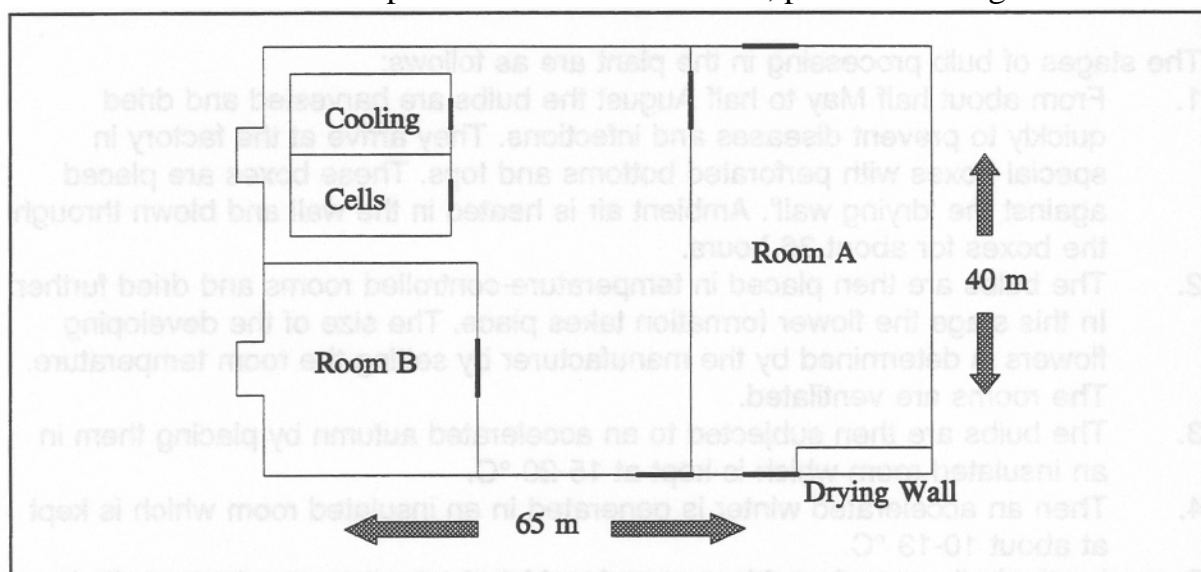
Fig. C.1   Location and dimensions of rooms A and B.

After harvest, the bulbs are dried to prevent infections. The drying takes place in the summer with ambient air which is heated and led through boxes containing the bulbs. Next, the bulbs will undergo an artificial autumn and winter cycle through conditioning at higher and lower temperatures. Afterwards, when the market requires so, loads of bulbs can be warmed up again to let the flower come up. Although the heat demand is high, the demanded temperature levels are low. For that reason this kind of processes is in principle well suited for application of thermal solar energy [1,2,3]. In the summer, the drying of the bulbs causes a high peak in the heat demand of the plant. In the winter there is a lower maximum in the heat demand, the minimal demands are in spring and autumn. It has seemed attractive from the beginning to include a heat store of sufficient size to enable long-term storage. By collecting and storing the excess part of the solar heat in spring and autumn the operating time of the collectors could be increased.

C.3.2 The Heat demand

An assessment of the heat demand pattern of the company 'Dames en Werkhoven' is presented in this chapter. Firstly a description of the various stages of the process are given, but this is restricted to the load pattern of the parts of the factory that are most interesting for solar energy application. After the installation of the solar system, a shift in operation to these parts of the factory is planned. The foreseen heat demand is thus different from (and larger than) the present energy consumption.

C.3.2.1   The bulb drying and conditioning processes

The stages of bulb processing in the plant are as follows:
1.   From about half May to half August the bulbs are harvested and dried quickly to prevent diseases and infections. They arrive at the factory in special boxes with perforated bottoms and tops. These boxes are placed against the 'drying wall'. Ambient air is heated in the wall and blown through the boxes for about 36 hours.
2.   The bulbs are then placed in temperature-controlled rooms and dried further. In this stage the flower formation takes place. The size of the developing flowers is determined by the manufacturer by setting the room temperature. The rooms are ventilated.
3.   The bulbs are then subjected to an accelerated autumn by placing them in an insulated room which is kept at 15-20 °C.
4.   Then an accelerated winter is generated in an insulated room which is kept at about 10-13 °C.
5.   Lastly, bulbs are placed in a room in which the temperature is controlled at about 25 °C and illuminated. The leaves grow and the bulb s develop.
Only the large two rooms (A & B) are considered for the solar system. Taking also into account the many smaller rooms would have meant a large increase of piping and installation work for the solar system but a small increase in system performance.

C.3.2.2   The drying wall

The drying wall is a large construction that is installed alongside one of the walls of Room A. It consists of five sections, each equipped with a water-to-air heat exchanger for heating the air and two fans for blowing the heated air (150000 m^3 per hour for the total installation) through the boxes with bulbs. The auxiliary heat is delivered by a gas-fired heating circuit, design temperatures 90/70 °C. A thermostat in the outward air of every section controls the heating conditions, one section of the wall will be used to keep Room A to the desired bulb conditioning temperature.

The solar system will deliver heat to the air in the drying wall by means of five extra water-to-air heat exchangers, identical to the existing ones and placed on top of them. This means that the existing system will remain intact and it will be used as auxiliary heating for the solar system. The solar-driven heat exchangers will act mostly as air preheaters for the present system.

C.3.2.2.1   Drying season
From half May to half August the wall will be operated for drying newly harvested bulbs. All sections of the wall will be in operation continuously. Ambient air will be drawn in and heated up in the heat exchangers. The desired temperature of the air is dependent on the ambient temperature in the following manner:

Ambient Temperature (°C)	Demanded Temperature (°C)
< 13	23
13 - 25	T(ambient) + 10 °C
25 - 35	35
> 35	T(ambient), no heating

The minimal (23 °C) and maximal (35 °C) temperatures are prescribed by the desired development of the bulbs.

C.3.2.2.2   The rest of the year
Outside the above period, the heating wall will be used to heat up Room A for the conditioning of bulbs. Only one section of the wall will be active since this will be sufficient to heat the room. In this period the inlet air will be recirculated from the room. Because of the noise produced by the fan, the wall will be switched off during working hours (monday to friday, 8:00 to 17:00).

The desired room temperature is in the range of 15-24°C dependant of the month of the year and if drying is required or not.
Room B is used for conditioning bulbs at various temperatures. Previously, the room is heated by an air heating system with fans and heat exchanger.

From the viewpoint of bulb conditioning, a floor heating system is a good alternative. Also, from the thermal solar point of view, the low return temperatures of a floor heating system are advantageous. For these reasons this is a good option to include in this system.

The demanded temperatures in Room B are dependant of the period in the year but should always be kept from freezing and are in the range of 5-30°C.

C.3.2.3   The load pattern

The load pattern for the solar system is calculated based on the presented strategies and assumptions. The pattern is shown in monthly totals in figure C.2. The figure shows two main features:

      The large peak in the heat demand during the drying period.

      A lower peak in winter due to bulb conditioning (room heating). The minima are in the spring (April) and in the Autumn (second half of August and September).

It should be noted that in August the heat demand is almost only in the first half due to the drying. In the second half of the month, the drying is stopped and there is only a relatively small residual heat demand.

In the TNO report B-91-0610 dated 8 july 1991 [4] the feasibility study, the computer models and approach used is described in more detail then in this Appendix.
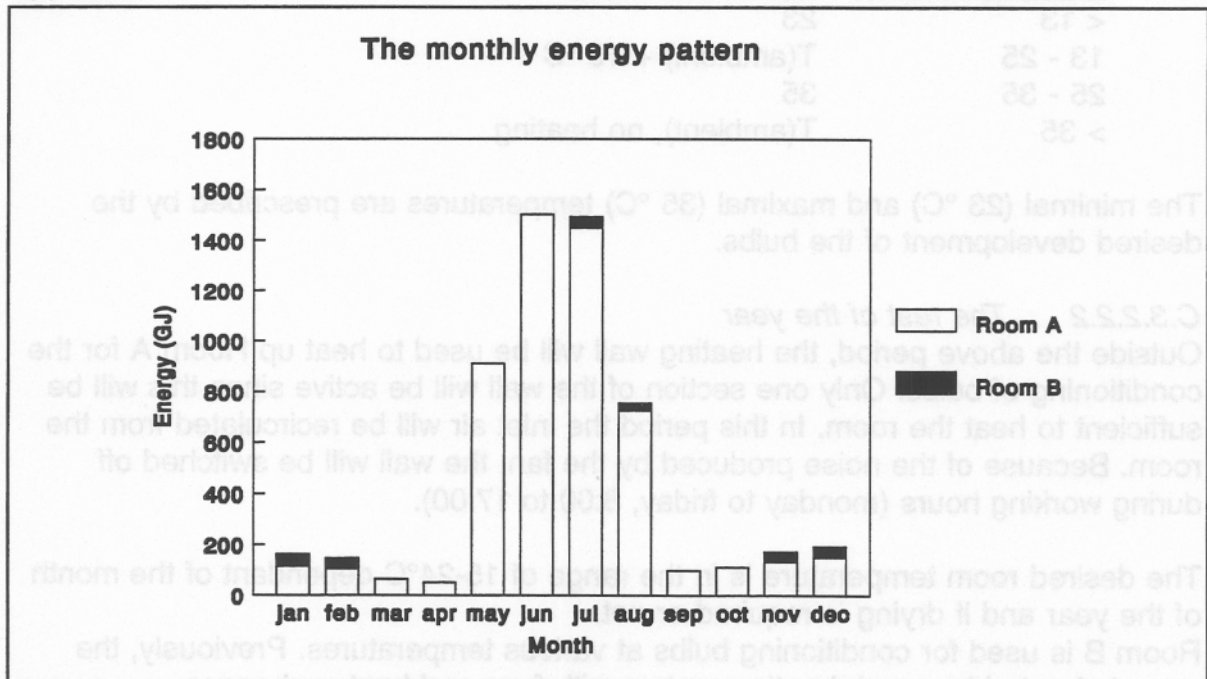
Fig C.2   Load pattern of the plant.

C.3.3 The System design.

Based on a detailed analysis of the energy needs of the factory, the heating load is about 5.7 TJ. Moreover, it is expected that in the new situation based on corporate expansion, there will be a significant heat demand in the spring and the autumn. The differences were caused mainly by the replanning of the processes and by the expected growth of the company's activities.
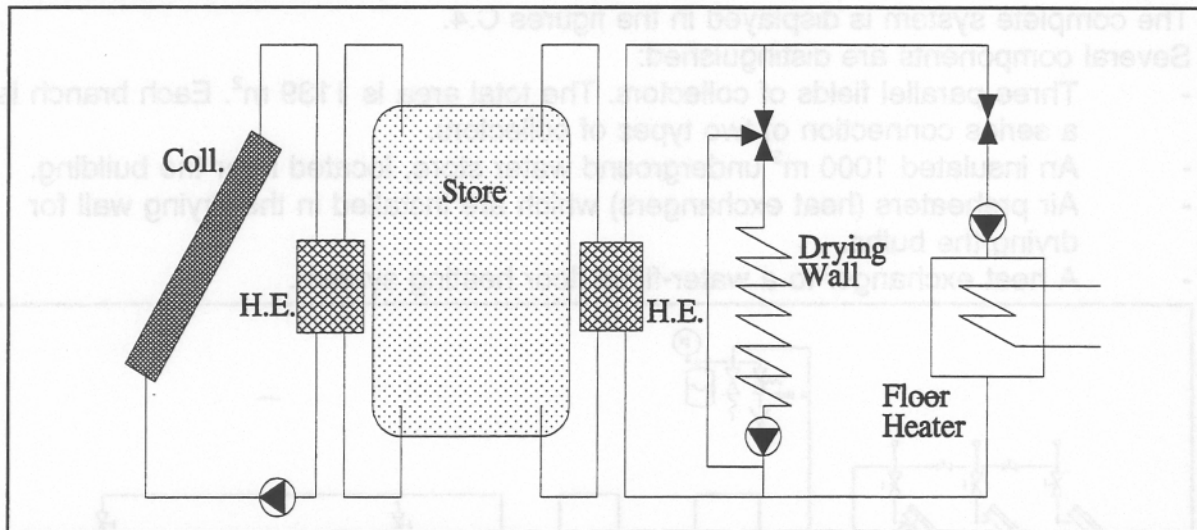Based on these figures the systems is globally dimensioned. In figure C.3 the system layout is presented.

Fig. C.3   Lay out of the system

Based on energy calculations of the solar system and the sensitivity analysis (see [4]) the lay-out of the system was proposed.
The global dimension are a collector field about 1000 m^2 and a store of about 1000 m$_3$.
A global comparison of the price/performance ratios of several systems was made, including a system with air collectors and no storage at all. The price indications used in this comparison were based on the information that was available at that time. The results of this comParison is given in table C.1.

System (Store)	Performance ind. (TJ/Year)	Coverage (%)	Price 10^3 hfl	Price/Performance
1000 m³	1.77	32	ca. 1000	0.56
100 m³	1.57	28	ca. 850	0.54
Air collectors, no storage	0.7	ca. 13	ca. 800	1.1
Solar Wall	0.7	ca. 13	ca. 650	0.9

Table C.1   Evaluation results of different system concepts.

The water systems with storage turned out to be considerably more cost-effective than the alternatives. Between a system with 1000 m^3 store (short/long term storage) and a system with a 100 m^3 store (short-term storage) the difference turned out to be small. However, from the research and development viewpoint, the long-term storage system is much more innovative and interesting. Also it is a good thing to have a solar coverage fraction as high as possible. For these reasons we decided to go on with the long-term store system, but also keep an eye open to the alternative with 100 m^3.

The complete system is displayed in the figures C.4.
Several components are distinguished:
-        Three parallel fields of collectors. The total area is 1139 m^2. Each branch is
         a series connection of two types of collectors.
-        An insulated 1000 m^3 underground water store, located near the building.
-        Air preheaters (heat exchangers) which are installed in the drying wall for
         drying the bulbs.
-        A heat exchanger to a water-filled floor heating system.
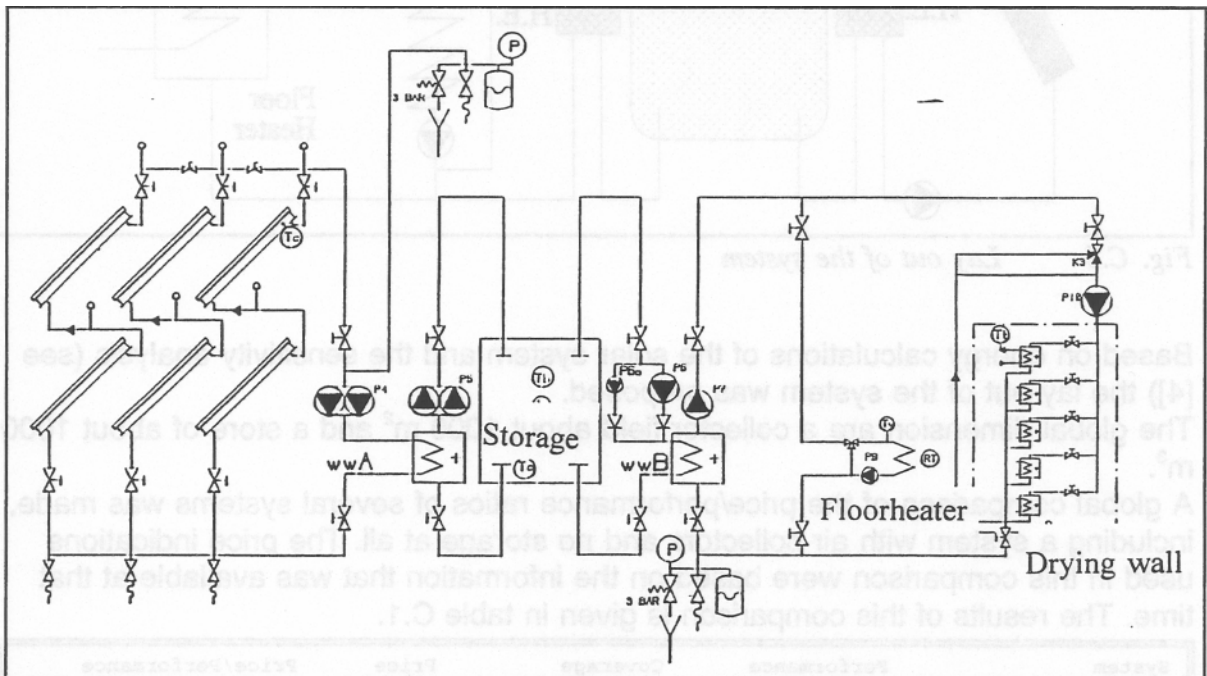
Fig. C.4   The complete layout of the designed system.

The heat, captured by the collectors, is stored in the water tank. The tank will be constructed in such a way that it can serve immediately as the floor (foundation) for a new building.
The heat transporting medium in the collector circuit is a 37 % glycol and 63 % water mixture. In the other circuits 100 % water is used. The store is separated from the rest of the system by heat exchangers. Inlet and/or outlet diffusors take care for the optimal stratification of the storage.

The collectors will be placed on the roof of the largest building and the building next to it. In this way the total area can be extended to 1139 m^2 without having to cover too many small roofs. The total collector area is divided in three fields, one field on each suitable part of the main roof (448 and 557 m^2) and one field on the smaller roof (134 m2).

Because of the intensive ground use in the area, special demands are put on the solar energy store. The store size of 1000 m^3 implies that the store will have to be put into the ground. The requirement of the company owner is that the ground above the store will be available for a new company building. This is dealt with by including the foundation and a part of the floor of this future building into the store. The costs for such a store are higher, but there is also a financial advantage when the new building is realized. Moreover, a part of the store insulation can then be used in the building itself and the building will profit directly from the store losses.

Five air-to-water heat exchangers will form the solar addition to the drying wall. They will be placed directly in front of the conventional heater units and heat/preheat the incoming ambient air. If the air has not reached the desired temperature after passing these heat exchangers, the conventional heating system will switch on and heat the air to the desired temperature.

The floor heating system that is planned in Room B consists of plastic tubes which are covered by concrete. Heat exchanger C separates the water in these tubes from the rest of the system.

The three collector pumps and the pumps in the primary and secondary circuit of heat exchanger A are always controlled together. A normal Delta-T controller is used: when the collector plate temperature rises above the temperature in the lower part of the store + 15 °C, the pumps switch on. When the temperature difference drops below 1.5 °C, the pumps will switch off.

In normal use, the store temperatures will stay between 20 and 75 °C and the chance of overheating is small. If at any time the temperature in the upper part of the store rises above 85 °C, a thermostat switches the collector pumps on. At night time the collectors will then be used as coolers until the temperature in the store has dropped below 80 °C. At this temperature the 1000 m^3 store will have enough capacity again for the next day: the store size is such that on a day with a large solar irradiation and zero heat demand the mean store temperature can rise at most 3 °C.
Only when the electricity supply would fail for a long period, there is a chance that the collector fluid would boil. A safety valve is mounted to secure against high pressures.
In the drying season (from half May to half August) the wall is in operation continuously. The five additional heaters for the solar system will have a common control unit. In normal operation, they will deliver only a part of the heat demand.

The five conventional heaters are controlled individually to supply the remaining heating demand. On the occasions that there is a low heat demand, the hot water temperature to these heaters will be reduced by thermostat valve. When the store is too cold, the heaters will be switched on.
In the rest of the year only one of the five heaters is be active, the other four are switched off by manual valves. This one heater will heat up recirculated air from room A. The control will be the same as described for the drying season.

C.3.4 Price performance evaluation

<u>C.3.4.1   The thermal performance</u>

The results of the simulations and performance calculations are given for the final design of the system.
The main dimensions of the system are:
   A total collector area of 1139 m2;
   A store volume of 1000 m^3 (see above).
The totals of the calculated heat flows in this system for the simulated year are summarized in figure C.5.
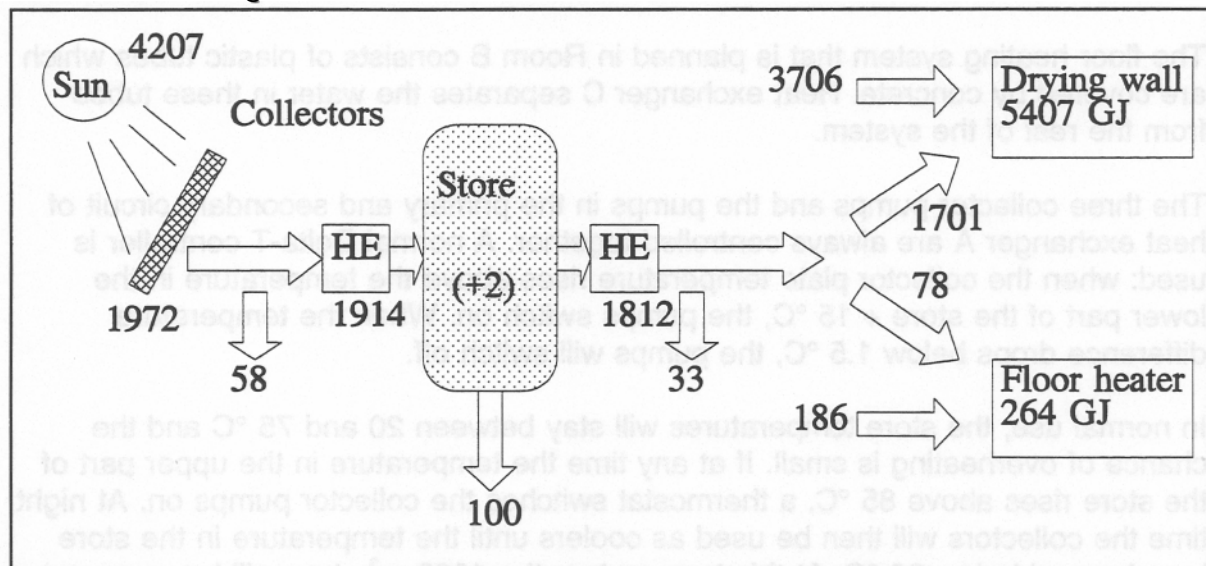
Fig C.5.   Yearly energy flows in the solar bulb drying system.

Some performance figures are:

Efficiency of collectors (incl. pipe losses):	46 %
Store efficiency:	95 %
Total system efficiency:	42 %.
Solar output in GJ/year:	1780
Solar coverage fraction:	31 %.

Store temperatures
(weekly averages)

——— Top   - - - - - Bottom
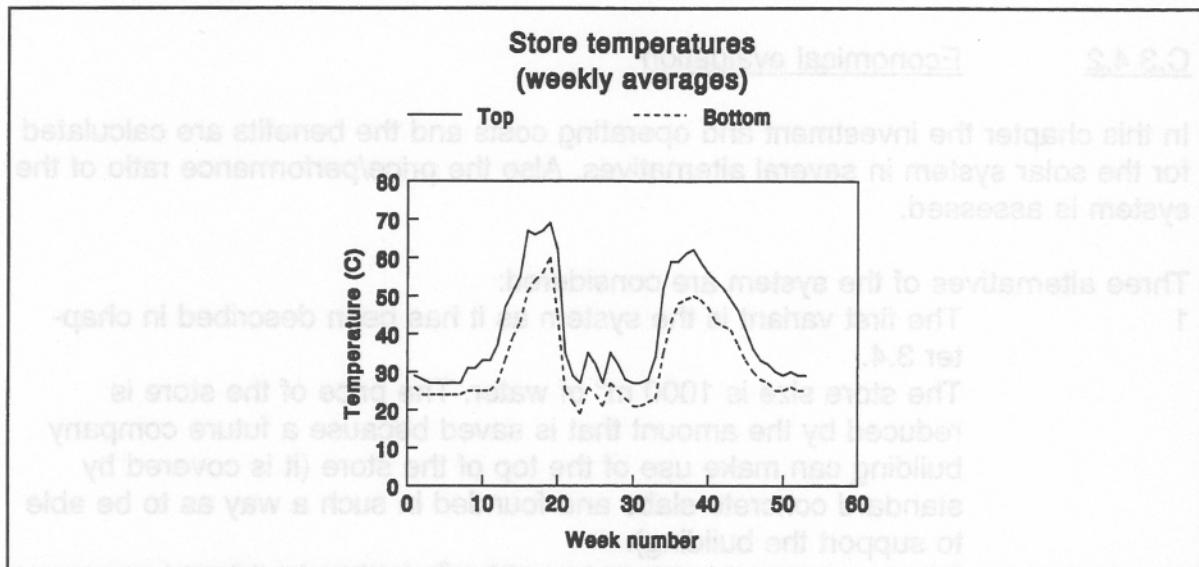
Fig C.6   Top and Bottom temperature storage

In figure C.6 the temperatures at the top and the bottom of the long-term store are shown during the year. It can be seen that in spring the store is loaded until the beginning of the drying season. During drying, the store delivers large amounts of heat until it is empty. In autumn (from the second half of august) the store is loaded again and the stored energy is used in the winter.

Figure C.7. shows the coverage of the load by the solar system per month. The large energy output from the store at the beginning of the drying season is clearly visible.

■ Solar system   ☰ Total load
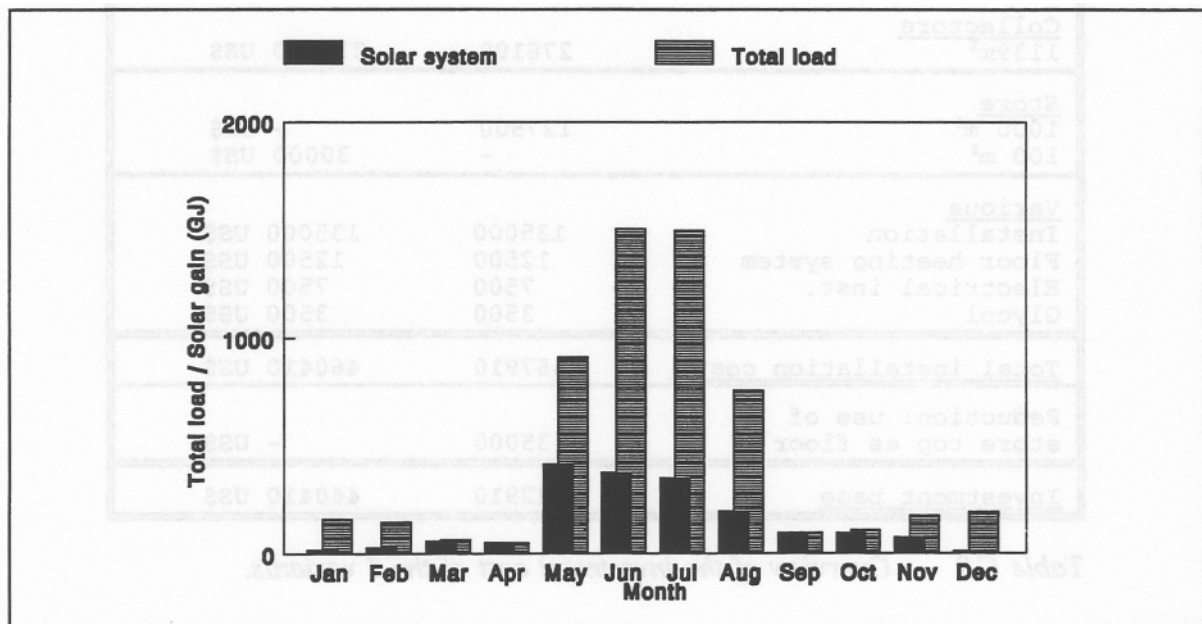
Fig C.7   Solar contribution

C.3.4.2   Economical evaluation

In this chapter the investment and operating costs and the benefits are calculated for the solar system in several alternatives. Also the price/performance ratio of the system is assessed.

Three alternatives of the system are considered:
1   The first variant is the system as it has been described in chapter 3.4.
          The store size is 1000 m^3 of water. The price of the store is reduced by the amount that is saved because a future company building can make use of the top of the store (it is covered by standard concrete slabs and founded in such a way as to be able to support the building).
2   The large store is reduced to 100 m^3 steel tanks (short term storage).
3   Lastly, an estimate of the price/performance ratio for a conventional expansion of the system is made. To obtain a clear comparison, this expansion is necessary to be able to achieve-the same drying capacity.

In the following overview the investment costs are shown for each of the three alternatives. All figures are in US$ at a course of 1 US$ = 2 Dfl.

Component	Alternative 1	Alternative 2	
Collectors 1139m²	278100	279100	US$
Store 1000 m³ 100 m³	127500 –	– 30000	US$ US$
Various Installation Floor heating system Electrical inst. Glycol	135000 12500 7500 3500	135000 12500 7500 3500	US$ US$ US$ US$
Total installation costs	557910	460410	US$
Reduction: use of store top as floor	35000	–	US$
Investment base	522910	460410	US$

Table C.2   Overview of the investment cost of the 3 variants.

In the following overview (table C.4) the cost/performance ratios of the three variants are evaluated. The calculations are based on:

- An investment subsidy level of 50 %;
- a system lifetime of 20 years;
- a yearly interest rate of 8 %;
- Auxiliary efficiency of 60 %;
- Natural gas price of US$ 0.25 / m^3 (0.0078 US$/MJ);
- Electricity price of US$ 0.10 / kWh (0.028 US$/MJ).

It should be noted that the solar energy system means an improvement of the performance of the heating systems in the factory. The natural gas and electricity price are the 1992 prizes in the Netherlands. (Due to taxation (ecological) these prices are rising by 10-20% from 1996-1999.)

Description	Altern. 1	Altern. 2		conventional system
Investment	522910	460410	US$	75000
Subsidy 50 %	261455	230205	US$	–
	261455	230205	US$	75000
Yearly annuity based on economic lifetime	26630	23447	US$	8762
Yearly maintenance costs	2000	2000	US$	1000
Total yearly fixed costs	28630	25447	US$	9762
Heat demand	5666	5666	GJ	5666
Solar contribution	1779	1575	GJ	–
Auxiliary heat	3887	4091	GJ	5666
Operating energy (electr.)	108	108	GJ	–
Total energy purchase	3995	4199	GJ	5666
Total yearly fixed costs	28630	25477	US$	9762
Yearly variable costs	53549	56201	US$	73652
Total yearly costs	82178	81647	US$	83414
Heat demand	5666	5666	GJ	5666
Price/performance ratio	14.5	14.4	US$/GJ	14,7

Table C.3   Overview the cost/performance ratios of the three variants.

The evaluation leads to the conclusion that the system with a short-term store (100 m^3) has a slightly better price/performance ratio than the two alternatives a 1000 m^3 store. The price-performance ratios of the solar systems are quite comparable with that of a conventional expansion of the capacity.

C.3.5 Conclusions

In chapter 3, the heat demand in the two largest process rooms of the company has been investigated. In this process, several foreseen changes in the use of the rooms have been taken into account. This has led to a much larger heat load for the solar system, then at the moment of inventarization is seen. The highest peak in the energy demand occurs between half May and half August. In the winter months, there is also a (lower) peak in the demand. The total future energy demand is estimated at 5.7 TJ/year.

This higher heat demand led to a reconsideration of the system concept, out of which a system with 1139 m^2 collector area and 1000 m^3 store volume was chosen as the best alternative. Also, a much smaller store size (100 m^3) could be considered.
It should be noted that the higher energy demand is connected to a performance improvement of the factory. The drying process can be accelerated and improved by using higher drying temperatures (10 °C above ambient temperature instead of 5 °C). This increased heating power is in fact one of the most important reasons for the increase of the heat demand.

The system as proposed consists of the above mentioned collector area, divided in three parallel fields each with two collector types. The heat is stored in a insulated, buried concrete water tank and used for preheating drying air and for a floor heating system in the largest conditioning room.
Model calculations resulted in a predicted performance of 1.8 TJ/year, which means a solar fraction of 31 %. The solar system efficiency is 42 %.
Variation of the store size showed that the system with this load pattern does not strongly react to this parameter. The decrease in performance when the store volume is brought down to 100 m^3 is about 11.5 %.
The collector area is much more important for the system performance. This is a consequence of the fact that the collector area is restricted by the available roof area. From the viewpoint of the large heat load, the collector area could have been larger.
The system is not very sensitive to changes in the heat demand or ambient temperatures. However, variations in the load shows a big influence

The price/performance ratio of the system has been evaluated: 14.5 - 15.0 US$/GJ (using 1 US$ = 2 Dfl). The price/performance ratio of a system with 100 m^3 short-term storage is almost the same: 14.4 US$/GJ assuming a 50% subsidy). This compares well to the price/performance of an expansion to the conventional system which gives the same heating capacity.
Because the difference in price/performance ratios of the considered systems are roughly equal, the preference should be given to the system with a 1000 m^3 store, because of its higher solar fraction and the special scientific interest and innovation of a store with 2 cycles per year.

C.4   PROJECT DESIGN

Based on the feasibility study an subsidy application for the EU thermie programme
was supplied and accepted. After approval of the project the realization phase
started in which the final system design was made based on the requirements of
the future owner, final cost calculations and pragmatic requirements. On a number
of aspect the system was adjusted.
In this paragraph the final system design is described.
In the collector circuit, primary side of the heat exchanger A, as well as in the
secondary side of heat exchanger B, the principle of an open distributor was
planned.
Between the floor heating system and the rest of the installation, there was planned
a hydraulic separation by means of the heat exchanger C.
The separation has been made in first case to prevent that incoming air (by
diffusion) gets into the rest of the installation. This should produce corrosion to
some parts of the installation.
In figure C.8 the design is presented.
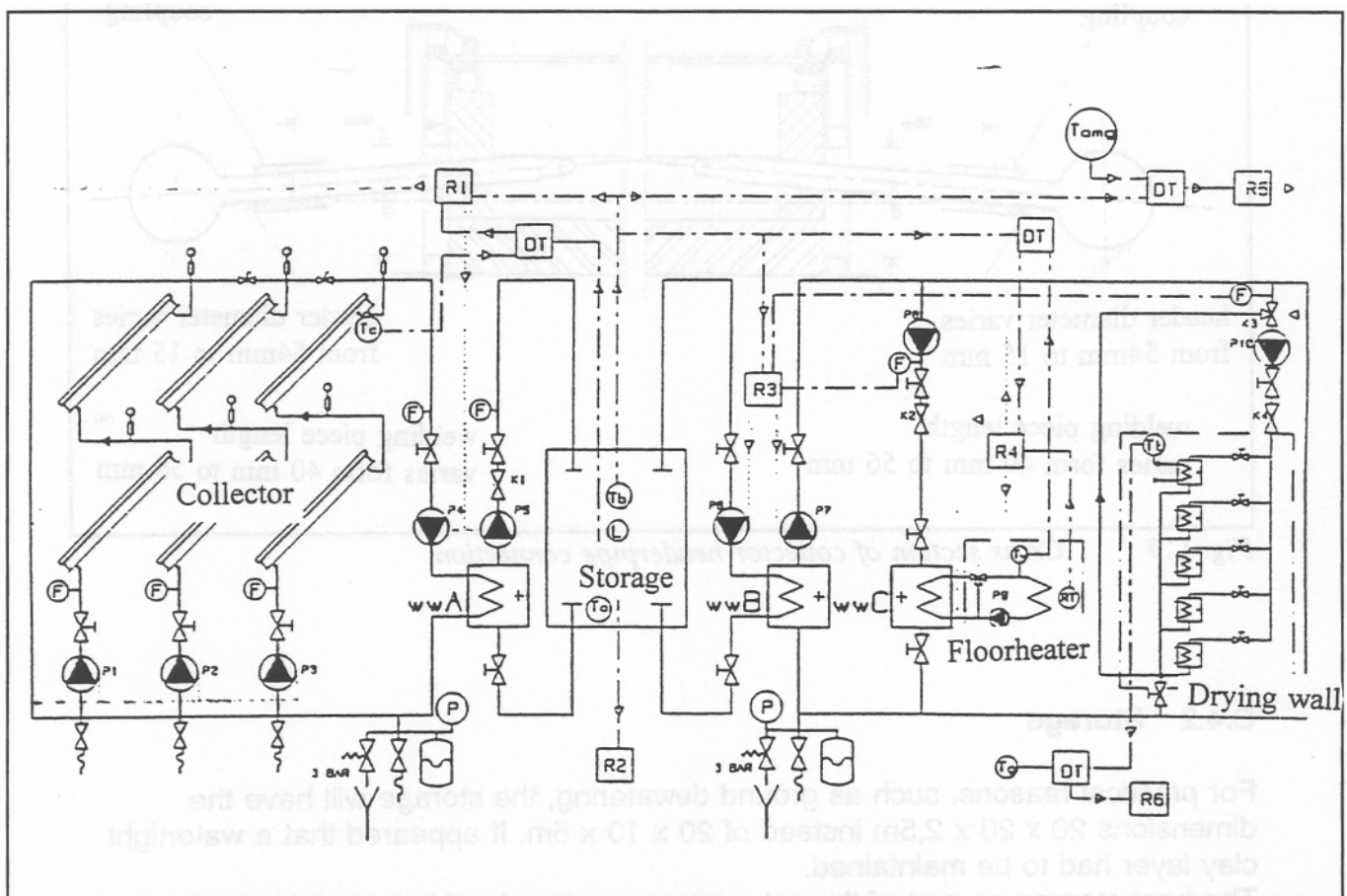
Fig: C.8   The scheme of the designed installation.

C.4.1 Collector array

In order to protect the collectors against freezing damage, this circuit will be filled with an anti-freeze solution.

The connection of the fields to each other will differ from the original concept.

The connection of the standard collector field (as one group) in series with the field with convection barrier causes a too high pressure drop. Therefore the normal collector fields and fields with a convection barrier will be connected in series, instead of the whole field.

The collector field consists of approx. 60% standard collectors and approx. 40% collectors with convection barrier. The collectors are the standard ZEN-collectors, at which an extra convection-barrier will be applied.

In the header piping several compensators will be used to prevent damage on the collector-connections by thermal expansion.

In figure C.9 a section is drawn of the collector-connection to the header.
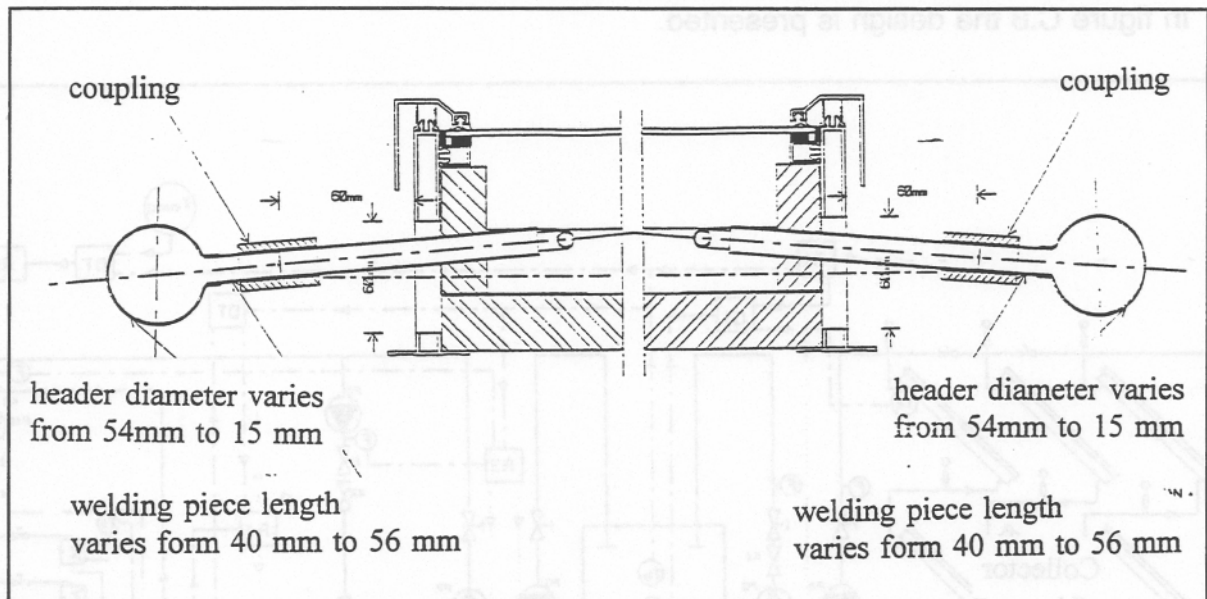
Fig. C.9   Cross section of collector-headerpipe connection

C.4.2 Storage

For practical reasons, such as ground dewatering, the storage will have the dimensions 20 x 20 x 2,5m instead of 20 x 10 x 5m. It appeared that a watertight clay layer had to be maintained.

The heat storage as part of the solar energy system for this project had to be designed specificly. The special requirements of the storage, as well as the specific soil and groundwater conditions, did not allow a standard cellar-construction.

The requirements are summarized as follows:
- content of approximately 1.000 m^3 water
- temperatures of 25-80 °C
- the top of the storage to be used as factory-floor in future
  durable insulation on all sites of the storage
- no water-leaking in or out the storage

The preliminary design of this storage assumed a concrete construction, in which the insulation material was integrated. The soil condition was expected to be mainly sand.
Before the final design was made, a ground and soil survey indicated a clay layer at 5m below surface. The original depth of the storage had to be adapted to this situation. The clay layer needed to maintain a permanent weight of at least 1.5m of sand. This did limit the planned depth of the storage. In order to create the 1.000m^3 content, the sizes of the storage were changed, leading to a surface area of 400m^2. The depth of the storage is 2.75m below surface.

The requirement that the top of the store should be used as factory floor made a foundation with concrete pilings through the store necessary. The original design assumed the walls of the storage to be insulated with 200 mm insulation material; the floor and roof of the storage with 100mm. The only thermal bridges from the storage to the surroundings are the concrete pilings (area: 250x250mm, 32 piles). In figure C.9 the design of the storage is given.
There are special requirements to take into account, once such a storage is build. Research of comparative projects learned that the conditions of other storages were different. The main difference is the fact that a waterstorage under water is created. The groundwater condition in most of the Netherlands varies between 200 mm and 800 mm below the surface. In the case of the Lisse project this was approximately 750 mm for most of the year.
As a result of this situation, one can decide for a leaking or a non-leaking construction. In any case leakages will be limited if the water level in the storage can be maintained at the same level of the groundwater.
This may look as an advantage, but in fact it is not. Two problems had to be solved:
1. If the storage ever will be emptied, the construction must remain stable (danger of "floating")
2. The insulation material around the storage has to be kept dry at all times.

Prevent the storage from floating
The first problem (floating) is a general one for cellars which are built "under water". Normally those cellars have an increased weight (by concrete) in order to prevent them from floating. In our case the normal operating conditions do not lead to any floating problems, since the storage is filled with water. Therefore it is not necessary to bring in a lot of extra weight. However measures have to be taken for those instances that the storage will be empty.

This has been solved by a permanent drain, which is located under the concrete storage-floor. By reducing the waterpressure under the concrete floor, the storage can gradually be emptied. During the construction stage, this will be tested. The water under the floor can be considered to be in a (leaking) compartment. The sites are formed by steel sheets, while the bottom part is formed out of a watertight clay-layer. The top site is the concrete floor. The reduction of pressure can be done by pumping more water out of this compartment.
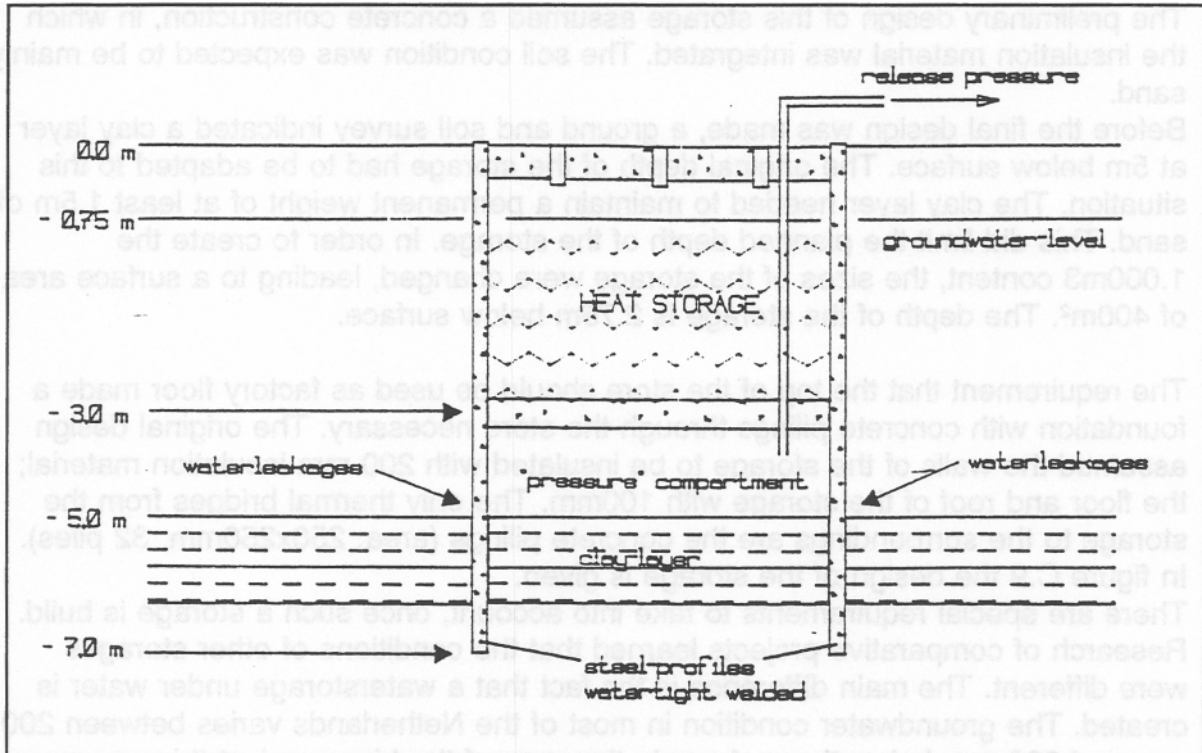
Fig. C.9   *Schematic cross-section of underground-storage*

Under water insulation
The second problem to solve, to keep the insulation material dry, looks easier as it is. There seem to be no insulation materials which are guaranteed for longer periods under water. Even Foam-Glass could not guarantee the insulation values over long periods of time, since the expected waterpressure on the foamcells was considered too high, in relation to the expected temperatures.
Each insulation material with closed cells has been considered. However it is expected for all those materials that eventually all cells will be "opened" by waterpressure and subsequently reduce their insulation value to zero.
The only reasonable solution is the use of (normal/cheap) insulation material, in dry-circumstances. These circumstances have to be created, which means a total watertight construction on both sides of the insulation material.
In order to do so, the preliminary thought was to create a non-leaking pit, in which the insulation is mounted and covered by a HDPE-foil (high-density poly-ethylene).

In order to create a 100% watertight construction on both sides of the insulation

material, it was decided to make a steel-plated box on the inside of the storage. This method is known as "boxing" and is generally used to make watertight constructions. In this manner, the insulation material is locked between a steel sheet on one side and HDPE-foil on the other side.
The risk of water coming into this construction is considered to be very low. In the construction phase this turned out to be different.
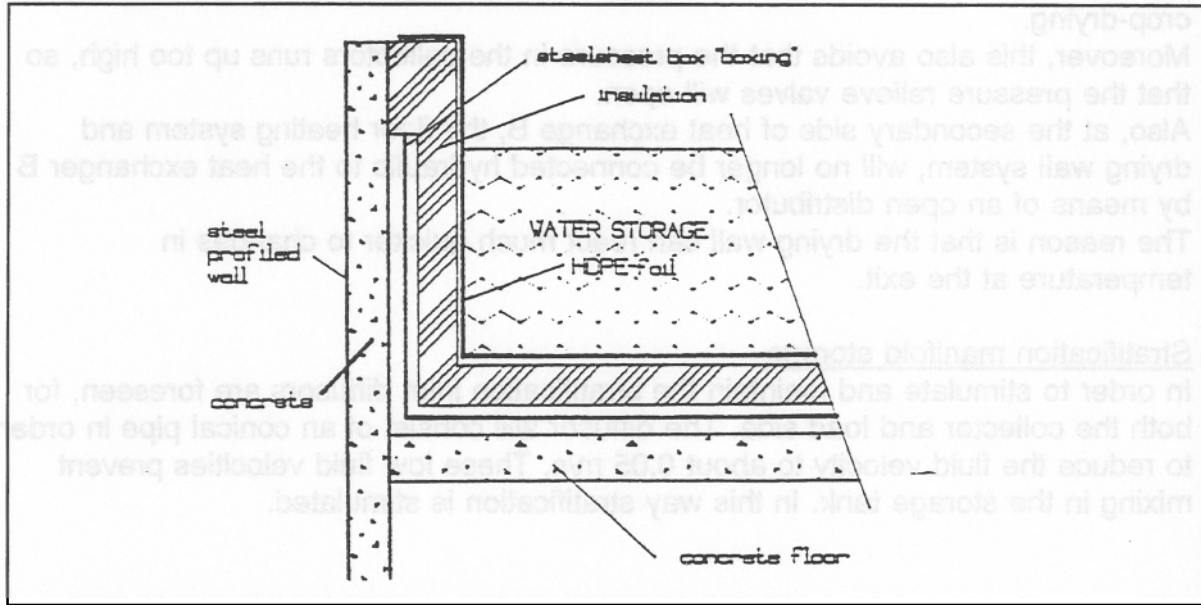In schematic, the construction is given in figure C.10.

Fig. C.10   Drawing of construction to prevent water to the insulation

C.4.3 Other system specifications

Floor heating system
After consideration with the producer of the floor heating tubes the decision was made to take out the hydraulic separation between the floor heating system and the rest of the installation. The guarantee period, as far as air diffusion is concerned, was that long (50 years) that the extra separation in the form of an heat exchanger (HX C, in the original design Fig. C.1) was no longer considered necessary. See for the consequences figure C.B.

Control system
Except for some simple adjustments, there have not been made any changes. A central computer will be used instead of separated control units. This central computers is due to the control of the drying process already available.

Pump and pipe system
To safe costs, there has been decided to feed the collectors with one pump instead of four pumps.
This means that the hydraulic connections from the heat exchanger to the three roofs will not be made through an open distributor.

This will cause a much more simplified pipe system, with less pumps and for that reason the costs will be less.

The roofs still will be connected to the heat exchangers in parallel.

To get a regular wear of the pumps, they will be switched over one by one. Moreover, if one pump fails, the other pump can take over the pumping without causing a total stop of the installation. The control system will give a signal if one of the pumps fails. This will avoid a great loss of energy, that could be collected for crop-drying.

Moreover, this also avoids that the pressure in the collectors runs up too high, so that the pressure relieve valves will open.

Also, at the secondary side of heat exchange B, the floor heating system and drying wall system, will no longer be connected hydraulic to the heat exchanger B by means of an open distributor.

The reason is that the drying wall can react much quicker to changes in temperature at the exit.

Stratification manifold storage

In order to stimulate and maintain the stratification inlet diffusors are foreseen, for both the collector and load side. The diffusor will consist of an conical pipe in order to reduce the fluid velocity to about 0.05 m/s. These low fluid velocities prevent mixing in the storage tank. In this way stratification is stimulated.

C.5   PROJECT REALISATION

C.5.1 Collectors

To apply the right convection barrier (teflon), different factories were approached. Also the University of Gothenburg (Sweden) and a Swedish manufacturer were contacted, to get information about the realisation of large collector fields with application of extra teflon layers. One of the problems, established by these firms, is the delicacy to tearing at sharp edges. Second problem is the enormous expansion coefficient and the creep of this material. Because of this, after some time the teflon layer will drop onto the absorbers. Also static electricity can cause problems, because the Teflon layer will then possibly be attracted to the glass cover of the collector.

After gathering information from the different collector suppliers, especially in Sweden, a method was developed to attach the teflon layer in the solar collector. The main points in this method are stainless steel wires in a distance of about 0.2m from each other, on top and below the teflon foil. At the sides of the collector, the teflon is clicked between aluminum profiles.

On top of the roof of the buildings so called U-profiles are mounted, in which movable plastic blocks were placed. On top of these plastic blocks the collectors are attached. By this method the collectors can be moved in a horizontal way, so that the connection of the header afterwards can take place in a very simple way.

To protect the collectors with a convection barrier against overheating in stagnation, during the period the installation is not filled with anti-freeze, the cover glazing of these collectors are sprayed with a special white chalk paint. This paint will automatically disappear after a few months with rain-water

As example of the distribution of the two types of collectors over the three different roofs figure C.12 roof 3 is presented.
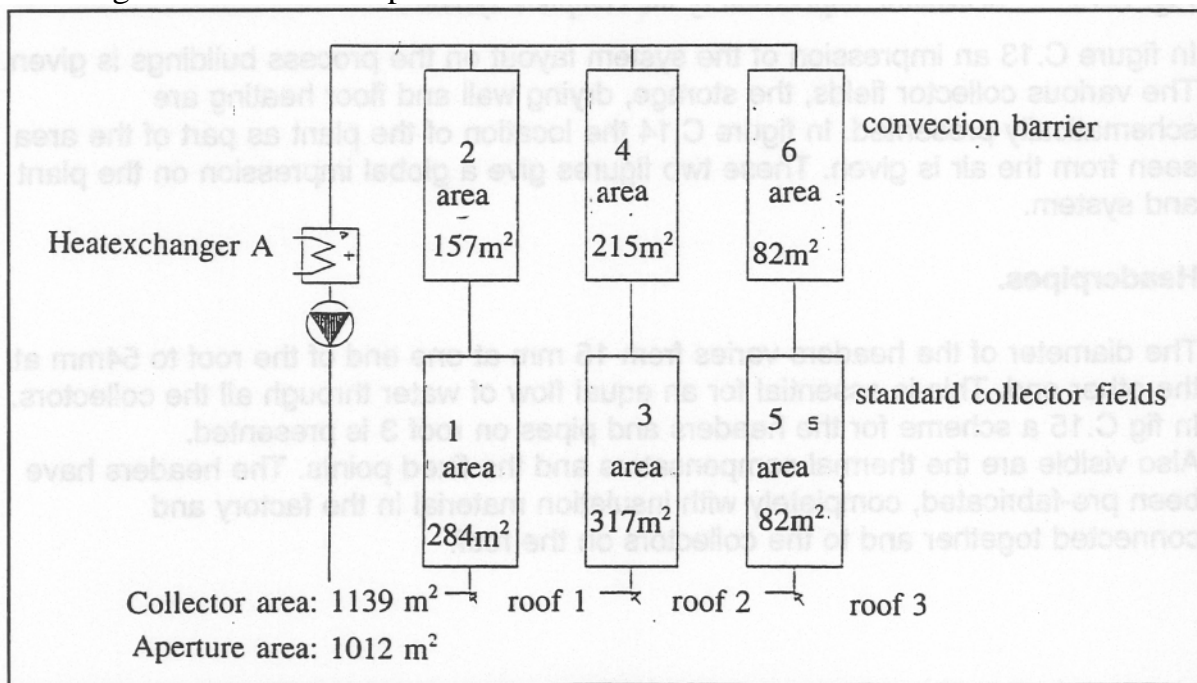

Fig. C.12   Distribution of the collector fields on roof 3.
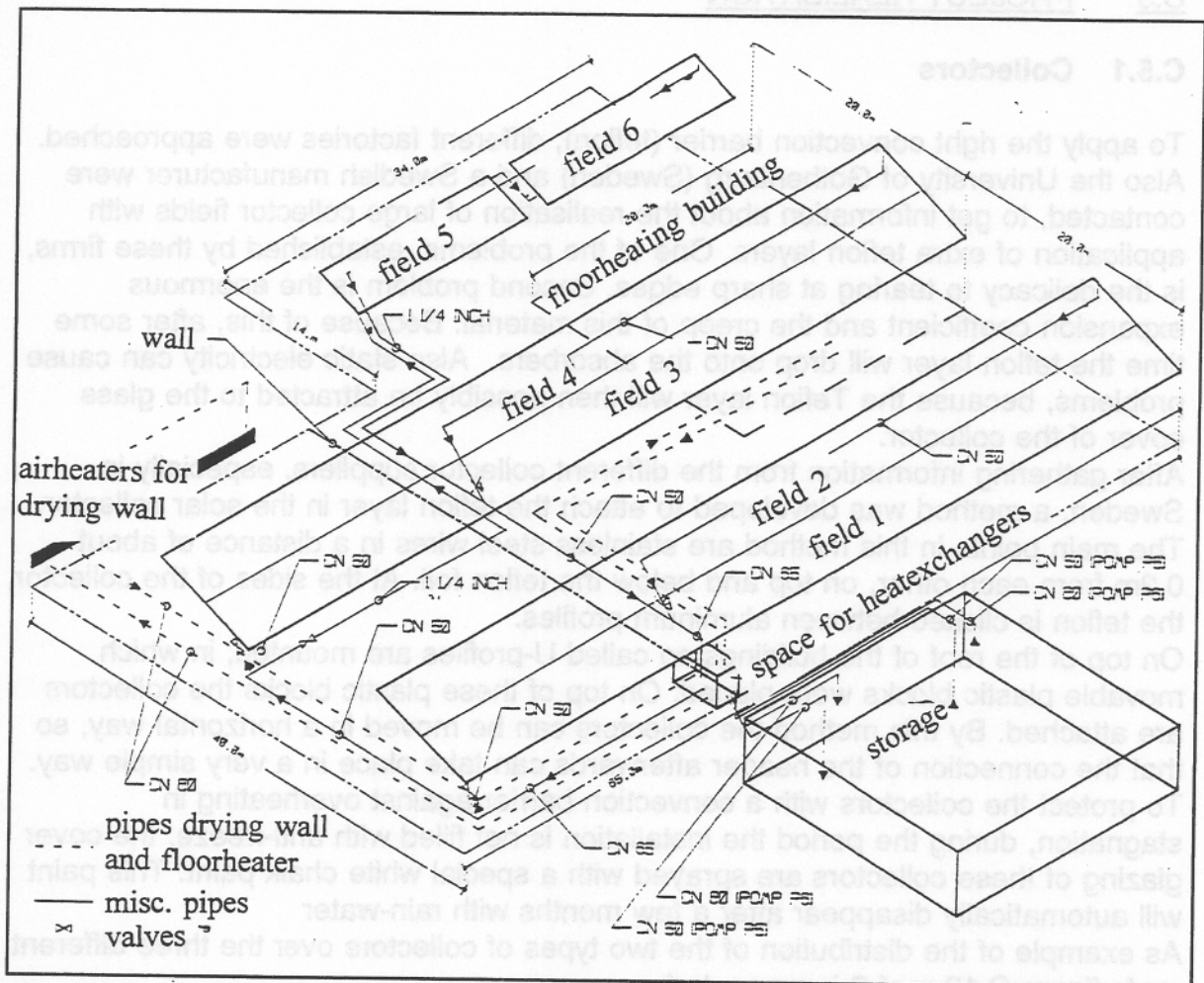
Fig. C.13   Schematic impression of the complete system .

In figure C.13 an impression of the system layout on the process buildings is given. The various collector fields, the storage, drying wall and floor heating are schematically presented. In figure C.14 the location of the plant as part of the area seen from the air is given. These two figures give a global impression on the plant and system.

Headerpipes.

The diameter of the headers varies from 15 mm at one end of the roof to 54mm at the other end. This is essential for an equal flow of water through all the collectors. In fig C.15 a scheme for the headers and pipes on roof 3 is presented.
Also visible are the thermal compensators and the fixed points. The headers have been pre-fabricated, completely with insulation material in the factory and connected together and to the collectors on the roof.
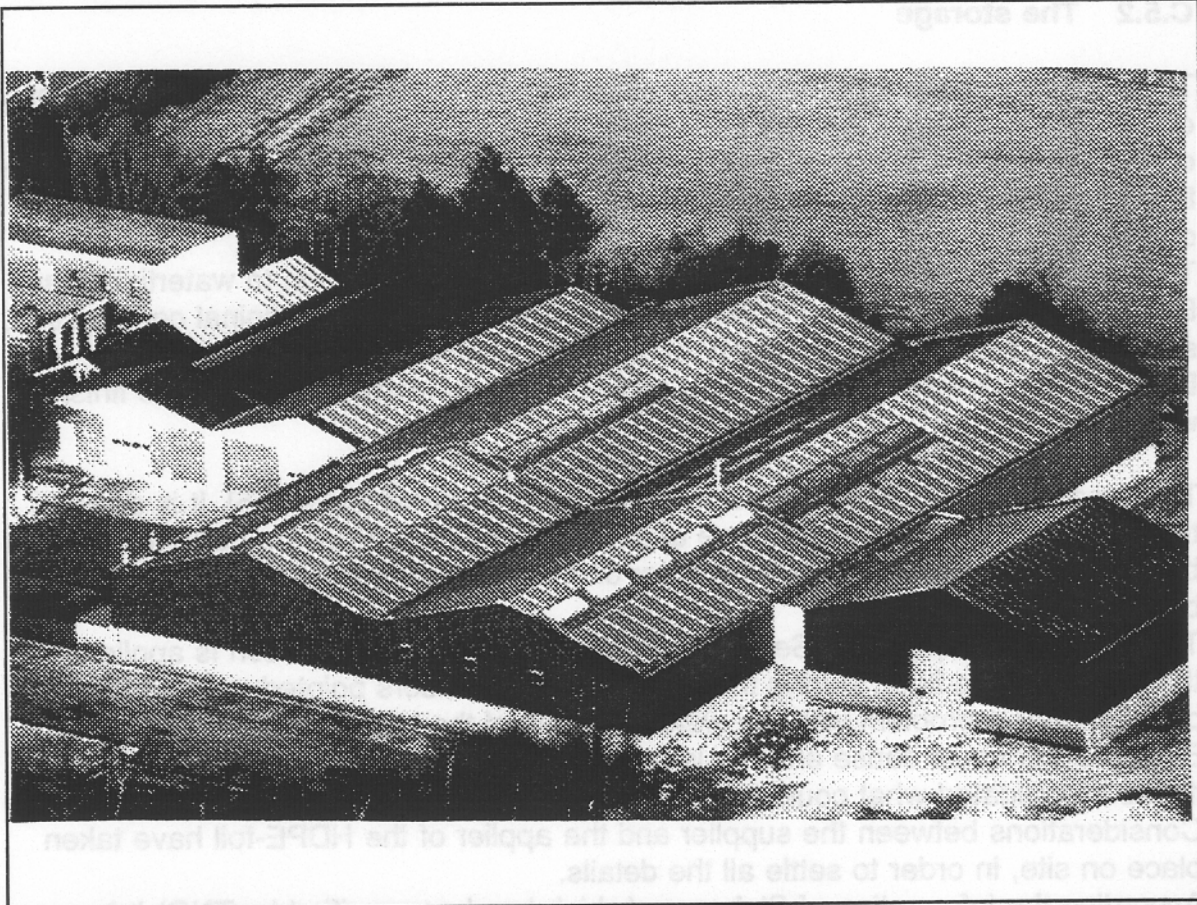
Fig. C.14   Aerial photo of the Lisse Solar system. The storage tank is located under the
                building attached to the right hand side of the main building
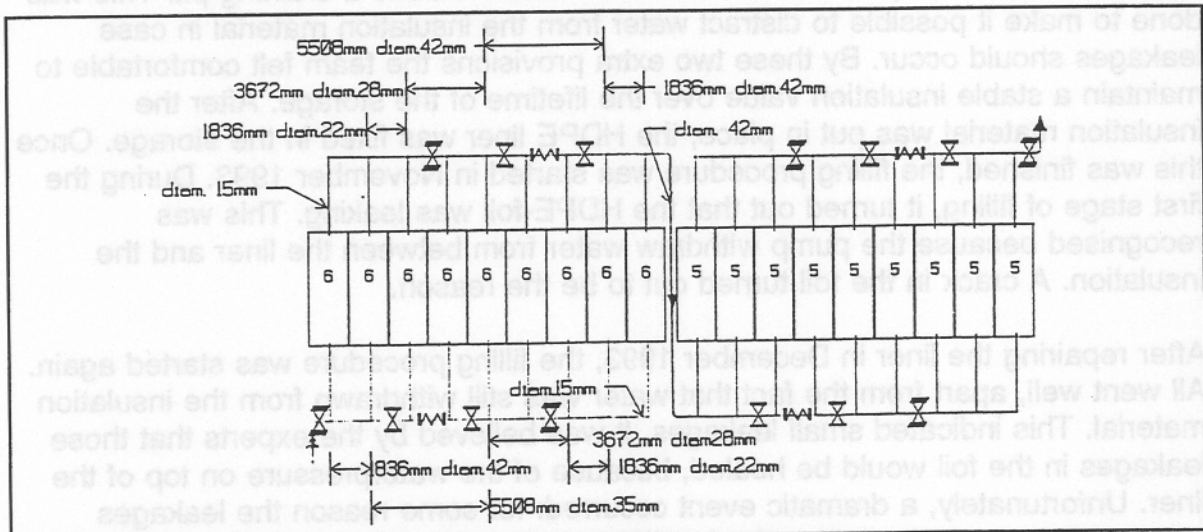

Fig. C.15   Scheme of headers and pipes on roof 3.

C.5.2 The storage

The construction work of the storage started in april 1993. During the construction of the pit, it happened that the drain-pump failed for a short term during construction of the concrete floor. Leakages in the connection floor/steelsheet were the result. The steelsheet itself has been completely watertight by welding all connection.
This incident showed clearly the vulnerability of the construction to watertightness. Even if the storage was made waterproof again, based on the original construction, serious doubts about the durability of this watertightness are risen.
Due to the leakages during the floor construction, the expected date to be finished was delayed.

The progress was evaluated and reported to the involved parties [5]. It is decided to re-arrange the strutting-structure and to build the midpart of the concrete floor before the storage will be drained. After draining the storage, the construction will be adjusted.
The boxing was applied in September 1993. After this the insulation is applied to the walls and the floor. During the job one of the advisors pointed out that there could appear a problem with the watertightness of the HDPE-foil.
Because this could cause enormous problems, the construction work stopped and it was investigated what could be the consequences of this fact.
Considerations between the supplier and the applier of the HDPE-foil have taken place on site, in order to settle all the details.
According the information of Stybenex, (which has been verified by TNO) it is decided to increase the insulation thickness, to compensate the most probably occurring water saturation of the polystyrene. In this way the heat resistance will be maintained, even if the insulation has filled itself with water.
At that moment also precautions have been taken to build a draining pit. This was done to make it possible to distract water from the insulation material in case leakages should occur. By these two extra provisions the team felt comfortable to maintain a stable insulation value over the lifetime of the storage. After the insulation material was put in place, the HDPE liner was fixed in the storage. Once this was finished, the filling procedure was started in November 1993. During the first stage of filling, it turned out that the HDPE-foil was leaking. This was recognised because the pump withdraw water from between the liner and the insulation. A crack in the foil turned out to be the reason.

After repairing the liner in December 1993, the filling procedure was started again. All went well, apart from the fact that water was still withdrawn from the insulation material. This indicated small leakages. It was believed by the experts that those leakages in the foil would be healed, because of the waterpressure on top of the liner. Unfortunately, a dramatic event occurred: for some reason the leakages increased dramatically, letting the insulation material in the bottom float upwards. The result is that the insulation material and the liner floated upwards to the water surface. This brought the construction work back to where it started.

The construction of the concrete floor elements on top of the storage was finished. In this stage, a further evaluation of the reason why this happened took place and from there technical solutions for the constructions are developed, in order to prevent this to happen a next time.

Specially the durable insulation of the storage appeared to be the main problem. All the experts, including the supplier of the HDPE-foil were convinced that a watertight polyethylene skin as an inner liner of the storage could be welded watertightly. In practice it appeared not to be.

It can be concluded that the leakage of the weldings in the foil have caused all the troubles to be expected. The increase in leakage after a few days shall be investigated, but is probably caused by cracks in the foil around the piles. According to the law of Archimedes the insulation material will be forced to the top of the water level in the storage.

Because it appeared not to be possible to make a complete watertight liner a solution was chosen in which the insulation material is completely in contact with the water. On the side walls foamglass will be used, in which foamglass will be fully surrounded by a special kit. This protection kit will prevent the hot water from etching the foamglass cellular walls. The bottom of the storage shall be insulated with 300mm of polystyrene. The extra insulation thickness compensates the loss of heat conductivity of the polystyrene. To prevent the insulation layer on the bottom from floating upward, it will be covered with HDPE-foil for pressure equalization and a concrete layer.

The store was built according to the updated design [6]. The approach in this design was to simply get the problems solved: make a well insulated and reliable store using conventional and well known techniques.

The following techniques are mentioned:

> floating of the bottom-insulation is prevented by a concrete ballast slab over it.
> The under water side insulation is made with Corning Foamglass©.
> All leakage paths between ground water and storage water are sealed with rubber gaskets that swell when in contact with water.
> A two layer vapour-tight sprayed coating was applied on all surfaces above the water level to prevent penetration of water in the insulation and structural components of the ceiling of the store (= floor of the production building that is built meanwhile on top of the store)

The design proved effective. No problems were encountered during further construction and the store was taken in normal operation. Temperatures of 65 °C were reached in august '94.

The final store design showed the parameters given in table C.5.

Storage content	1000 m³
Seize	20 x 20 m
Height of the storage inside	3250 mm
Wall insulation	Foamglass 150 mm
Coating on wall insulation	PC 88
Floor (base) insulation	PS 300 mm
Floor ballast	Concrete 250 mm
Top insulation	PS 100 mm

Table C.5   The final parameters of the store.

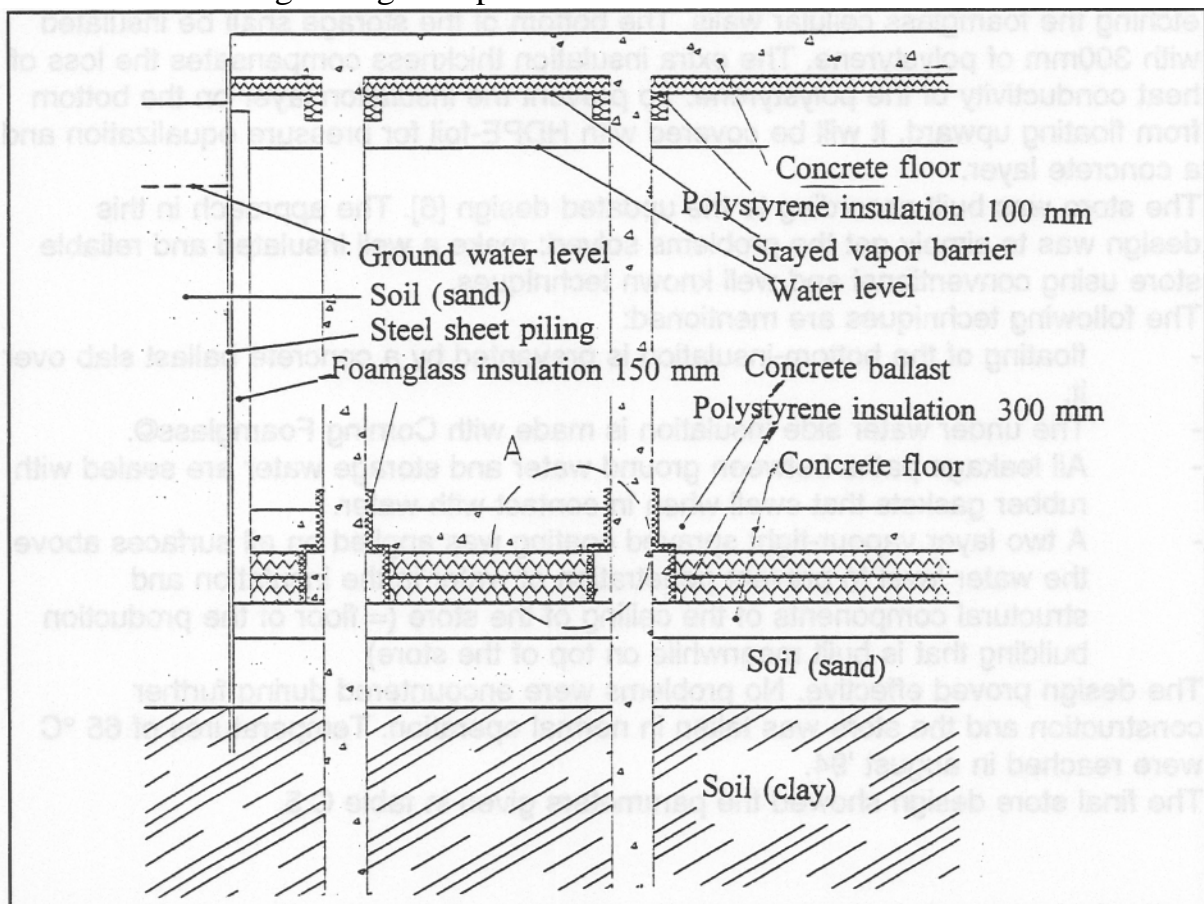In figure C.16 the design is schematicly given. In figure C.17 and C.18 some details of the storage design are presented.

Fig. C.16   Schematic presentation of the store.
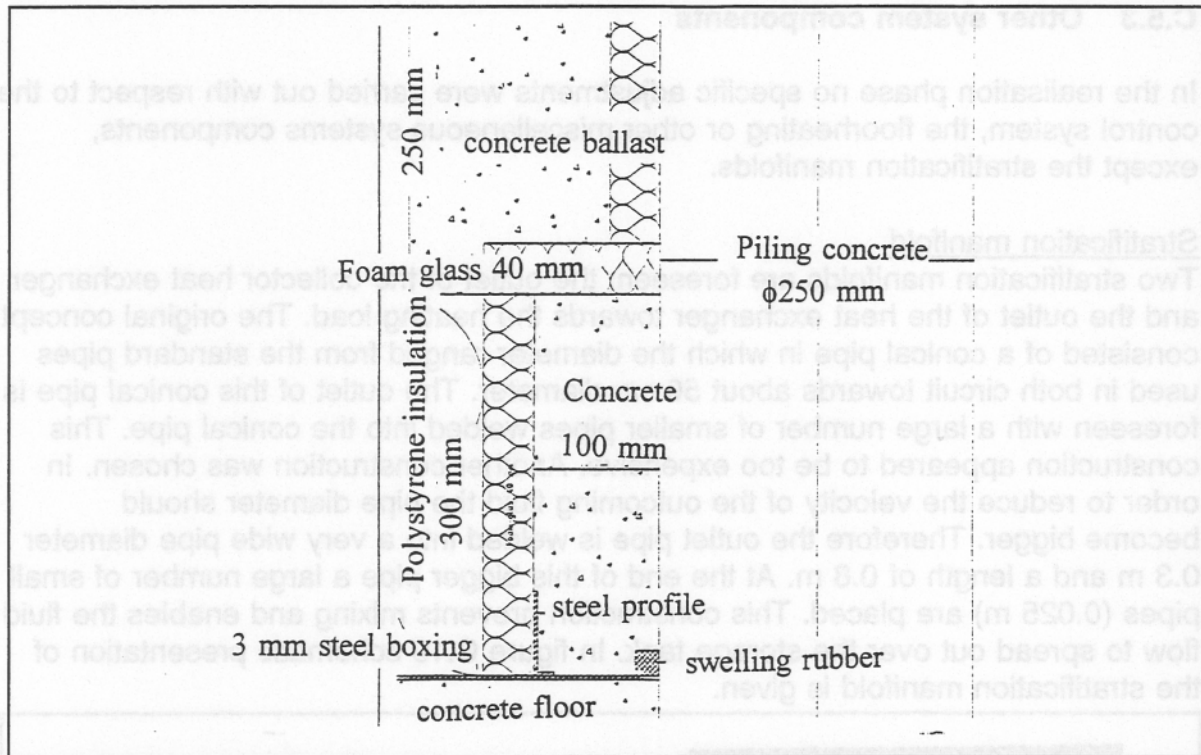
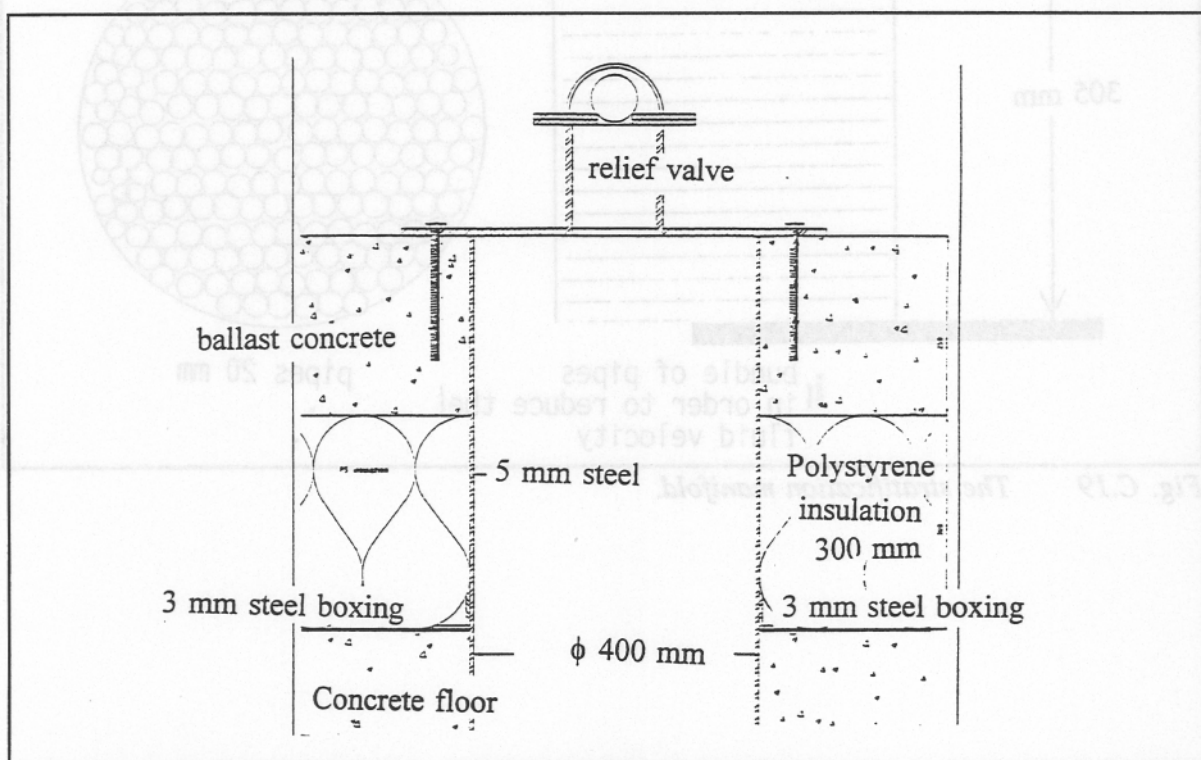Fig. C.17   Detail A of the storage, connection of the floor/base pilings.

Fig. C.18   The relief valve in the bottom of the storage.

C.5.3 Other system components

In the realisation phase no specific adjustments were carried out with respect to the control system, the floorheating or other miscellaneous systems components, except the stratification manifolds.

Stratification manifold

Two stratification manifolds are foreseen; the outlet of the collector heat exchanger and the outlet of the heat exchanger towards the heating load. The original concept consisted of a conical pipe in which the diameter ranged from the standard pipes used in both circuit towards about 50 cm diameter. The outlet of this conical pipe is foreseen with a large number of smaller pipes welded into the conical pipe. This construction appeared to be too expensive. Another construction was chosen. In order to reduce the velocity of the outcoming fluid the pipe diameter should become bigger. Therefore the outlet pipe is welded into a very wide pipe diameter 0.3 m and a length of 0.8 m. At the end of this bigger pipe a large number of small pipes (0.025 m) are placed. This construction prevents mixing and enables the fluid flow to spread out over the storage tank. In figure C.19 schematic presentation of the stratification manifold is given.
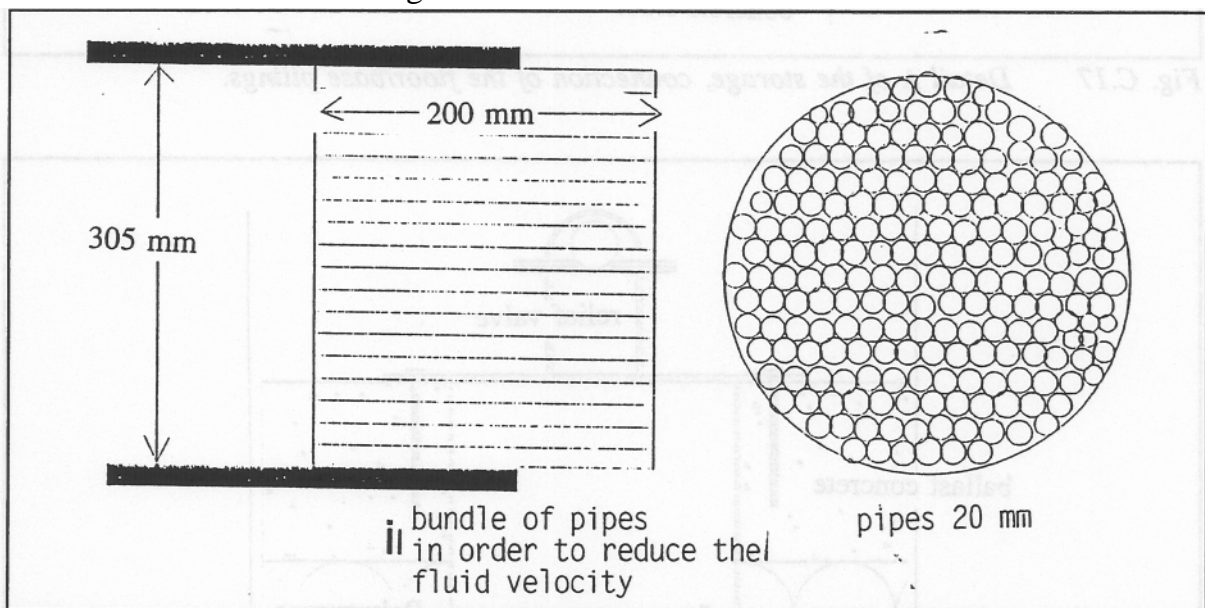

Fig. C.19   The stratification manifold.

C.6   COMMISSIONING

C.6.1   Collector circuit

All circuits were filled and tested. The flowrates in the circuits were adjusted on their setpoint-values. Some remarks:

The collector circuit was filled with water-propyleneglycol and flowrates through the three collector-fields were adjusted. A tank is installed to hold the water-glycol in case the circuit is drained by the action of the pressure-relief valve (a situation that can occur on a sunny day in case the circulation of the collectorcircuit stops due to pump-problems or power failure).

The store charge and discharge circuits gave problems : poor start-up of circulation due to air in pumps. One-way valves are installed and proved effective.

The collectorfields were visually inspected in february 1995. Some observations:

Some seams in the teflon foils in the collectors are ruptured.

The foil-support structure was designed allowing for this problem, therefore the ruptured Teflon foils are still effectively supported and function as intended.

Some absorbers look (partially) dirty.

As the result of inadequate insulation on the inlet and outlet piping of some of the collectors, wind could blow some organic material (fallen leaves) on the absorber surfaces. This causes the "dirty" look. However only a negligible part of the total absorber area is involved, the performance of the collectorfield will therefore not be influenced.

The problem is solved by applying adequate insulation on the piping.

Attacked insulation material on piping.

The neoprene rubber insulation on the piping of the collectors was finished with aluminized polyester tape. Contrary to manufacturer information, the tape is not weather resistant and is replaced by aluminum tubing.

Minor deformations of the absorbers.

The absorbers are somewhat deformed due to deformation and expansion of the polyurethane back-insulation. This is caused by the high stagnation temperatures that the collectors had to withstand in a long and hot summer period in which the circulation was switched off.

This deformation is not enough to affect the performance negatively. From now on this process is stopped, because the continuous circulation of the collectors prevents stagnation and the associated excessive heating of the absorbers and materials in the collectors.

After installation of the complete solar collectorfield including the headers, the system is pressurized and tested for leakages.

After the leakagetest the insulation of the headers is wrapped around with aluminium tape, to protect the installation against whether-influences.

C.6.2 The Storage

After some calamities during the initial construction, the design was changed. This design proved effective. No problems were encountered during construction and the store is taken in normal operation. Temperatures of 65 °C were reached in august '94.

C.6.3 The rest of the system

During the analysis of the first measurements the efficiency of the heat exchangers appeared to be low, only 50% efficiency. Further analysis showed that the heat transfer capacity was only 14 kW/K instead of the design value of 108 kW/K. Inspection showed that the heatexchanger was not installed in the counterflow but in the parallel flow configuration. This was corrected.

Commissioning of the floorheater showed a low heating capacity. The fine tuning of the mixing valve has taken some time, but is adjusted now into 10% recirculation and 90% flow from the storage. Therefore the floor heating could not be fully used.

C.7   MONITORING PROGRAM

C.7.1 Introduction

All the measuring equipment was installed during the construction and monitoring was started at the moment the complete system came into operation.
Due to the problems in he realisation of the storage the collector field has been temporarily connected to the bulb drying wall. This period was used to test the functionality of all the monitoring instruments.
In this period of about 6 months, the functionality of all the monitoring instruments was tested, with good results. The TNO-monitoring system proved also very useful, as (1) the flowmeters enabled accurate adjustments of the flowrates in the circuits and (2) it allowed accurate testing of the computer-control-system (called the EVAL-computer) that operates pumps and valves to guide the energy flows in the solar system.
During the first months of 1995, assuming enough sunshine is able to drive all circuits as intended and at the required temperature levels, the monitoring results will first be used to do a commissioning inspection on the system. This includes:
> analyze the performance and control of the collectorfields (i.e. lower than expected performance hints to uneven flowdistribution within the fields),
> analyze the heatloss of the store,
> analyze the functionality (UA-value) of the two liquid-liquid heatexchangers and the six air heaters.

After the commissioning, system flaws will be corrected and then the Solar System can be formally handed over to the customer Dames & Werkhoven.

Based on the monitoring period of about 1 year measuring results are available with respect to the solar energy contribution and the overall energy usage.
In figure C.18 the solar system and location of the instrumentation is given. The measurement are carried out with a Fluke datalogger and an industrial pc (heavy duty). The sensors used for the monitoring project are the following:
- Temperature
- Flow measurements
- solar radiation

Measurements are carried about every 30 seconds. The timestap for the data storage of the measurements is 5 minutes. Via a modem and telephone connection the data is sent from the measurement location toward the TNO test facility. The data is checked, registered and stored in the testfacility. The infrastructure and procedures of the test facility is used for processing, analysing and keeping the monitored data.
The measurement started in december 1994. This was not the most favourite period to start the measurements. The storage is cold, the solar radiation is low and there is a low heat demand of the bulbs drying plant. The first more detailed analysis could only take place during some nice days end February beginning March.

Commissioning of the system was partly already carried out at the end of the realisation phase and for the collector fields and drying wall during the period that the storage was not yet functioning.
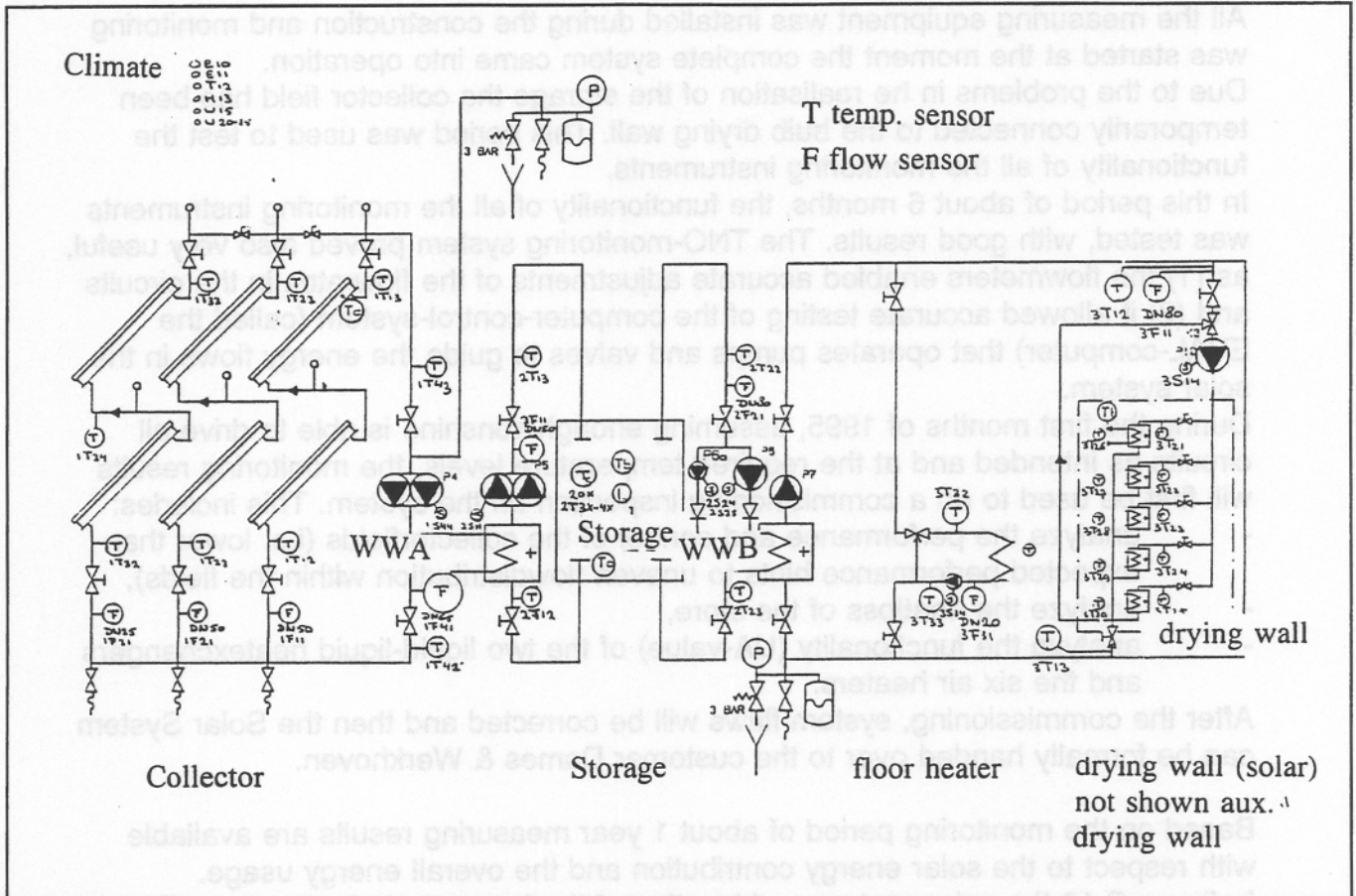

Fig. C.20   Location of the sensors in the system.

C.7.2 Energy load

The energy load of the system is based on the drying wall and the floor heating system.
Table C.6 shows the monthly results as measured in 1995.
The columns Drying wall and Floor heater give the dual energy load. The column collector is the netto collected energy delivered to the store. The energy charged or discharged is calculated on monthly average temperature differences and the column balance is the energy lost from the store.
The column Auxiliary is the energy delivered to the drying wall by the heatexchangers in the central heating circuit.

Month	Solar	TAmb	Collector	Drying Wall	Floor-heater	Store	Balance	Store Temp.	Auxil ary
	[GJ]	[°C]	[GJ]	[GJ]	[GJ]	[GJ]	[GJ]	[°C]	[GJ]
jan	78	4.5	12	0	7.4	7	-3	21.7	18
feb	131	7.0	34	0	4.6	1	28	22.0	0
mar	328	5.9	93	0	0.0	41	52	32.0	0
apr	435	9.0	126	32	0.0	63	32	47.2	12
may	641	12.7	235	167	0.0	10	58	49.7	138
jun	602	14.3	217	136	0.3	-10	90	47.2	69
jul	674	19.8	233	115	6.9	50	61	59.4	9
aug	614	19.6	195	74	-1.1	12	110	62.4	31
sep	288	14.6	51	11	-0.6	-18	59	58.0	32
oct	207	13.1	44	20	2.5	-49	70	46.2	6
nov	96	7.2	12	4	12.7	-47	43	34.8	4
dec	65	-1.0	2	1	5.6	-41	36	25.0	32
1995	4158	10.6	1253	558	38	21	664	42.1	321

Table C.6   Monthly energy flows and year results as measured in 1995.

Figure C.21 gives the year results in a graphical presentation, while figure C.22 the solar contribution to the system per month represents. Comparing this with the calculated results from the design study in figure C.6 shows large differences. The main deviation is the much lower heat load in the drying wall. This amounts to a factor 6 lower energy consumption than predicted. The design study already showed large fluctuations in energy use from year to year which could be as large as a factor 4 between monthly loads. At this moment the causes for this difference are analyzed. There are several deviations from the design study. The bulb drying process itself is very sensitive to the ambient air temperature and in 1995 all climatic records were broken being the longest and hottest summer ever in Holland. The control of the drying process has been changed since the design study as now the process is controlled by measuring bulb temperatures in stead of air temperature. Moreover, the possibilities of controlling the system and drying strategies have increased drastically due to the integration of the system control into the process computer. This also could account for a sharp reduction in the load. Also as the installation is meant to be in use for the next 25 years the owner expected a future expansion which is not yet visible in the process as the delay in finishing the store also delayed the progress of the new building on the top of the store.
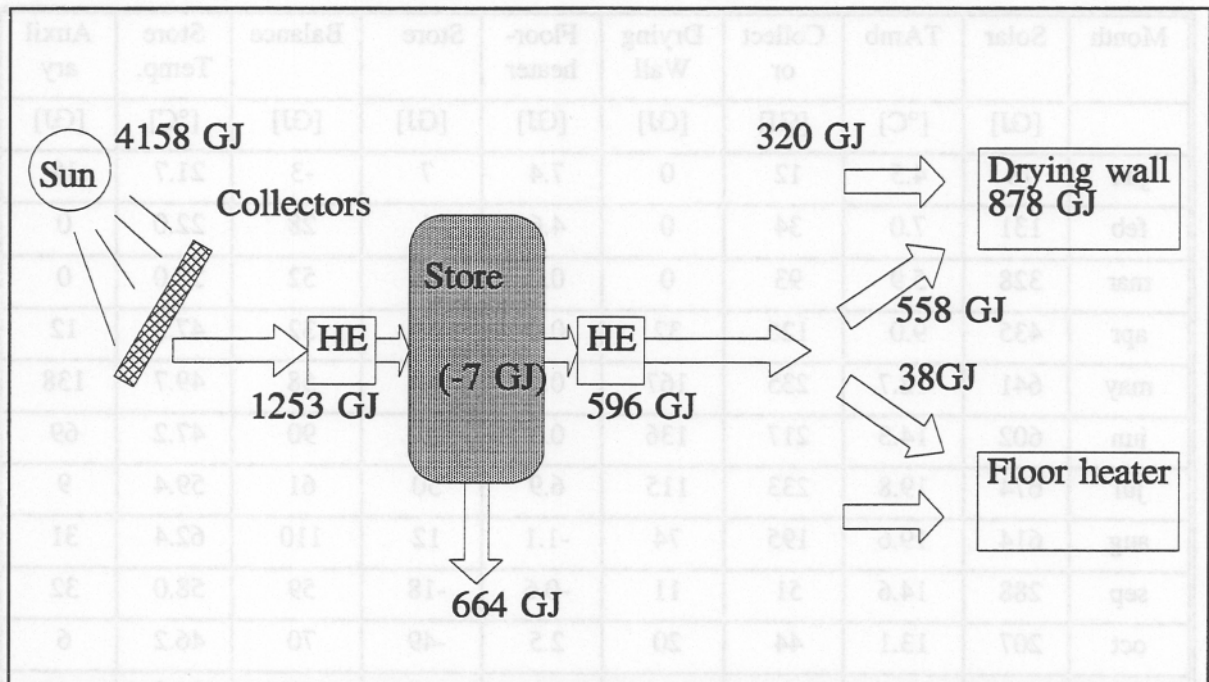
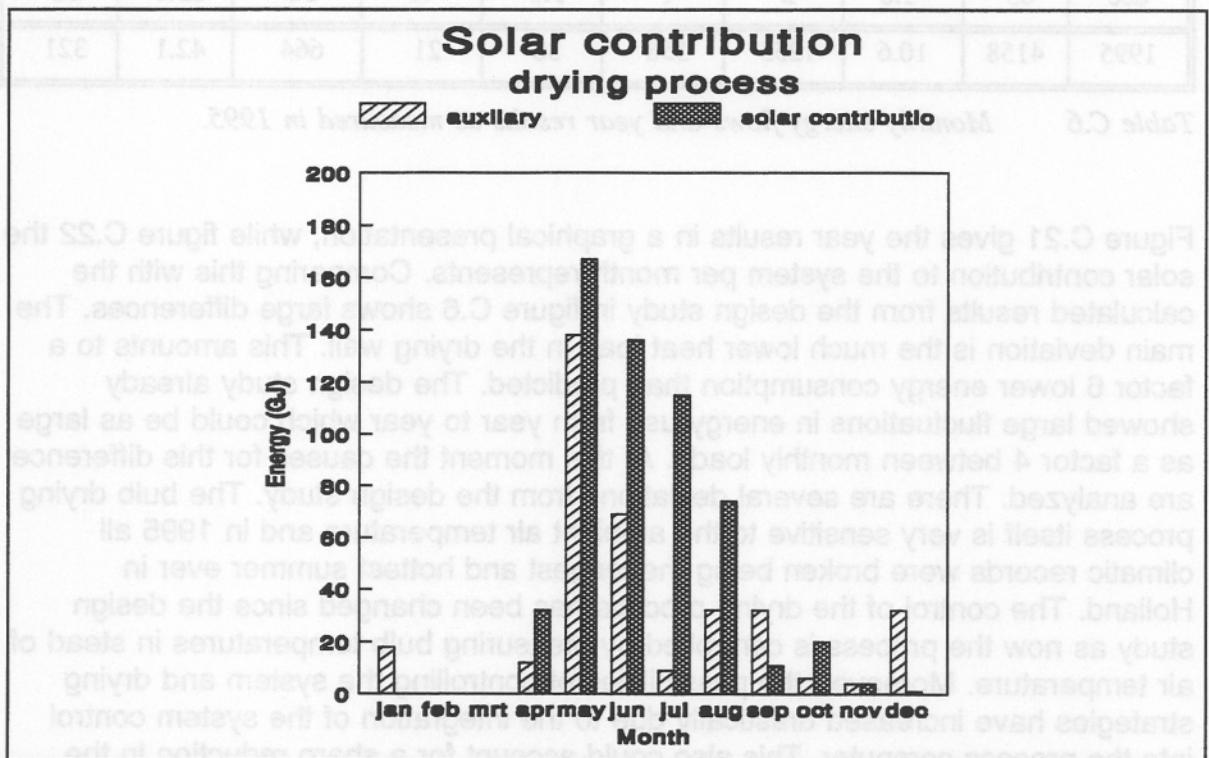Fig. C.21   *The energy year results of the solar drying plant.*

Fig. C.22   *Solar contribution to the energy load of the Lisse installation.*

In figure C.23 the measured upper and lower storage temperatures during 1995 are given.
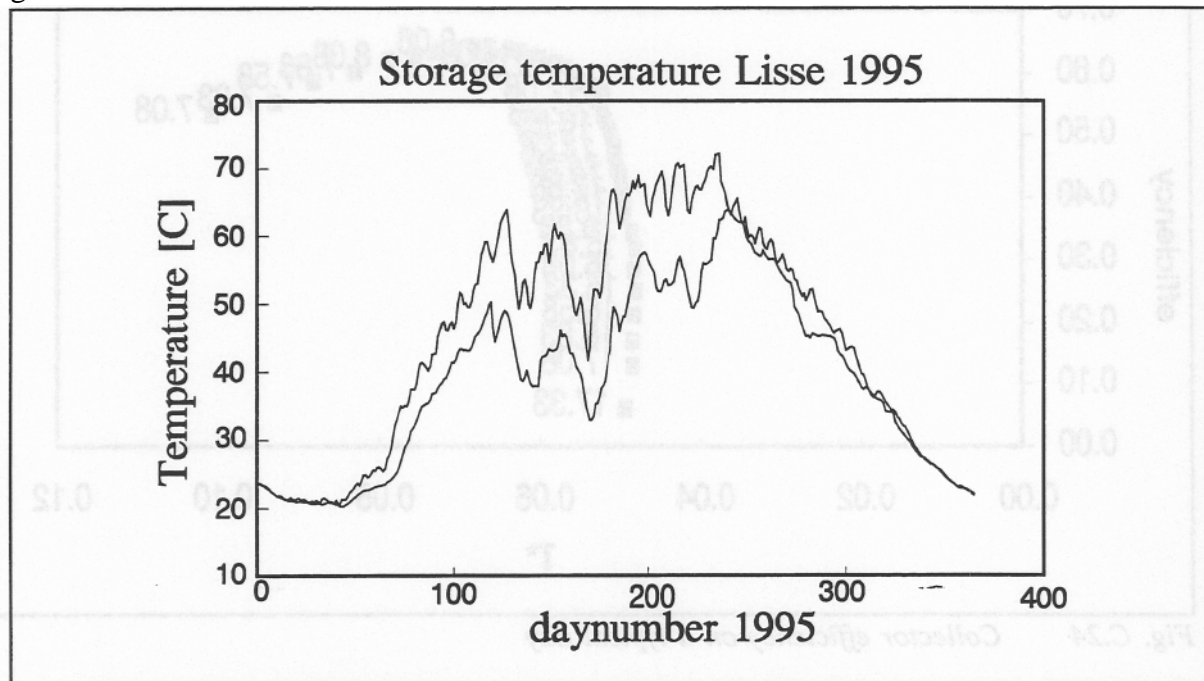

Fig C.23   Temperatures in the storage as function of the time in the year (1995).

C.7.3 Solar contribution

In figure C.21 the solar contribution to the drying wall and floor is presented. Due to the much lower energy use for the drying process the solar contribution is much higher than the use of auxiliary energy. This means that a solar contribution of 64% results to the drying wall. The total solar radiation amounts to 4158 GJ which is per m^2 about 10% higher than in the design study. The total system efficiency is only 14%. This low value is only partly caused by higher heat losses from the store. The store efficiency is only 47% whereas 95% was expected from the design study. One of the reasons for higher losses was found to be a partly defective roof insulation on the top of the store. An inspection in winter showed a relative small area of about 20 m^2 where the roof insulation had come off. On this area a very effective vapour condensation process can take place, decharging the store via the concrete top of thes storage to the air in the building on top.
The reason leading to the failure of the bond of the glue is not known at this moment.
Calculation of the energy loss of the storage per m^2 surface area show an loss of 0.6±0.2 W/(m^2.K) where the most recent calculations during finishing of the store showed 0.35 W/(m^2.K), reparation of the insulation will reduce the losses somewhat.

collector efficiency day 180
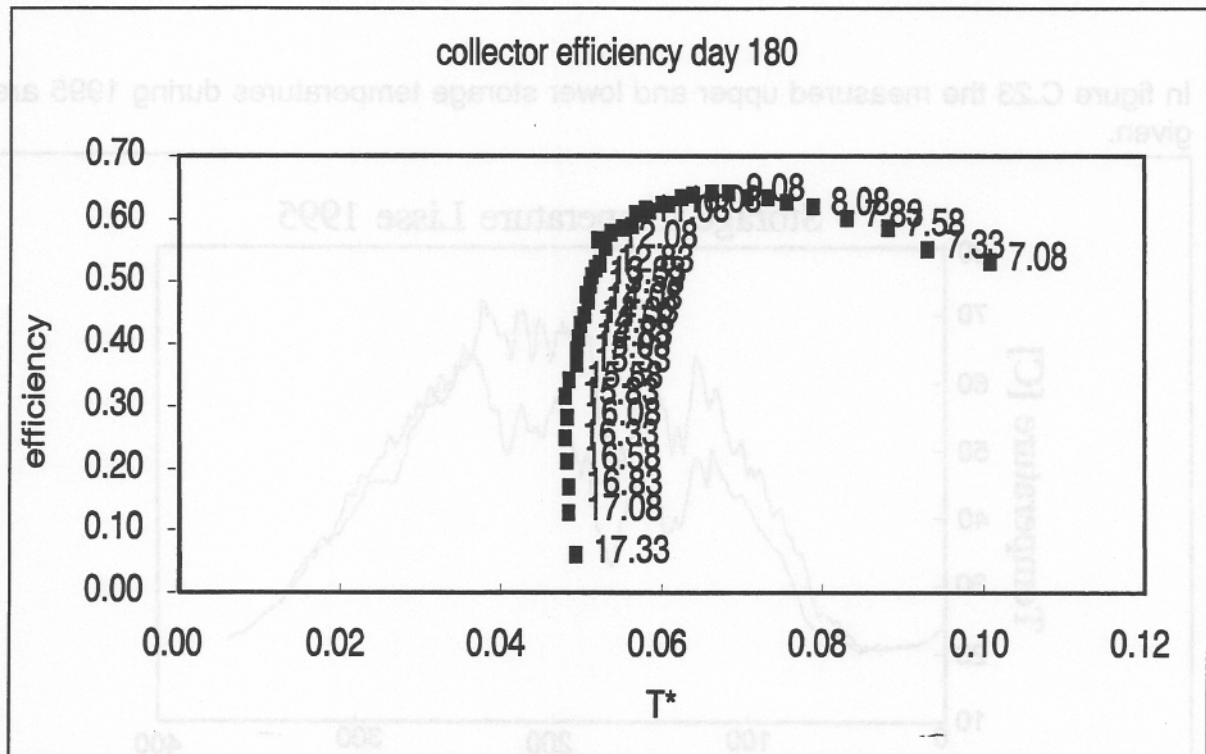

Fig. C.24   *Collector efficiency on a typical day*

C.7.4 Collector and system efficiency

The flow through the collector fields is adjusted at 0.005 kg/(s.m ^{2}) using the monitoring system for actual measurement in the circuits during control.
The average collector efficiency amounts to 30% during 1995. This low value is partly caused by the low energy use but there are more reasons. The analysis on delivery of the system already showed some signs indicating problems with efficiency in the collector. During the summer the pressure in the collector circuit was raised to original level on several occasions but it kept dropping due to blowing off of by the relief valves.
A full analysis of day 180 shows the efficiency on a ideal sunny day in one of the fields. Collector efficiency rises with time of day along the expected collector efficiency curve until about 9 o'clock. After that hour the efficiency starts dropping until end of day is reached. The instantaneous collector power versus solar insolation also shows a loop on the day. The reason is that part of the collectorfield reaches boiling temperature due to too low pressure in the collector circuit. This eventually causes collectors to drop into stagnation one by one reducing the effective collector area.
Once a collector is switched off it remains in that state during the rest of the day. As the total collector flow to the field remains constant.

The rest of the field is getting a higher flow resulting in lower temperatures in the collector circuit. Calculations with a collectormodel show a reduction of about 15% in collected energy on this day. However such a process is expected to be of more random nature then the measurements indicate. The behaviour doesn't differ much neither between fields nor from day to day, which is strange because the internal partitioning of the three fields is totally different, indicating that the origin of the problem can be lying in small differences in collectorflow.

Apart from this problem the smaller field 3 is shadowed by its orientation on a roof lying two meters lower than the other fields. On winter days and early morning hours this collector is switched on too early as there is only one pump in the system. For this reason the ΔT is set to a higher setpoint in winter.

C.7.5. The heat exchangers

The system uses three heat exchangers. This is the glycol-water heatexchanger between collector and storage, the water-water heat exchanger between storage and load and the water-air heatexchanger in the drying wall.

The performance of the heat exchangers to the storage is much lower than design values but also lower than their specifications. During commissioning it appeared that the heat exchanger A (WWA) in the collector circuit was wrongly installed. After correction the efficiency was established and is 90 %. This means a heat transfer capacity of 75 kW/K instead of the design value of 100 kW/K. In figure C. 25 the effectivity of heat exchanger 1 as function of the power is given.

Heat exchanger B (WWB) is placed between the storage and the drying wall and or floor heating. The efficiency is about 70 % and the heat transfer capacity is 32 kW/K. The overall design value is 170 kW/K. In figure C.26 the effectivity of heat exchanger B as function of the time is presented. The flows on the primary and secondary side of the heat exchanger are not the same. The flow through secondary circuit is dependant of the number of preheaters in the drying wall are used. Moreover, the secondary flow can be very low if only a small number of air heaters is used. The flow in the primary circuit however is constant high. This causes mixing in the store and a lower efficiency in the heat exchanger. Measures to improve this process will be taken.

The much lower measured performance of the heat exchangers in the load circuit will bring the system performance into the problem zone. Enabling much higher temperatures in the load circuit and this will limit system performance when the drying wall is in full operation under less favourite conditions with low storage temperatures.
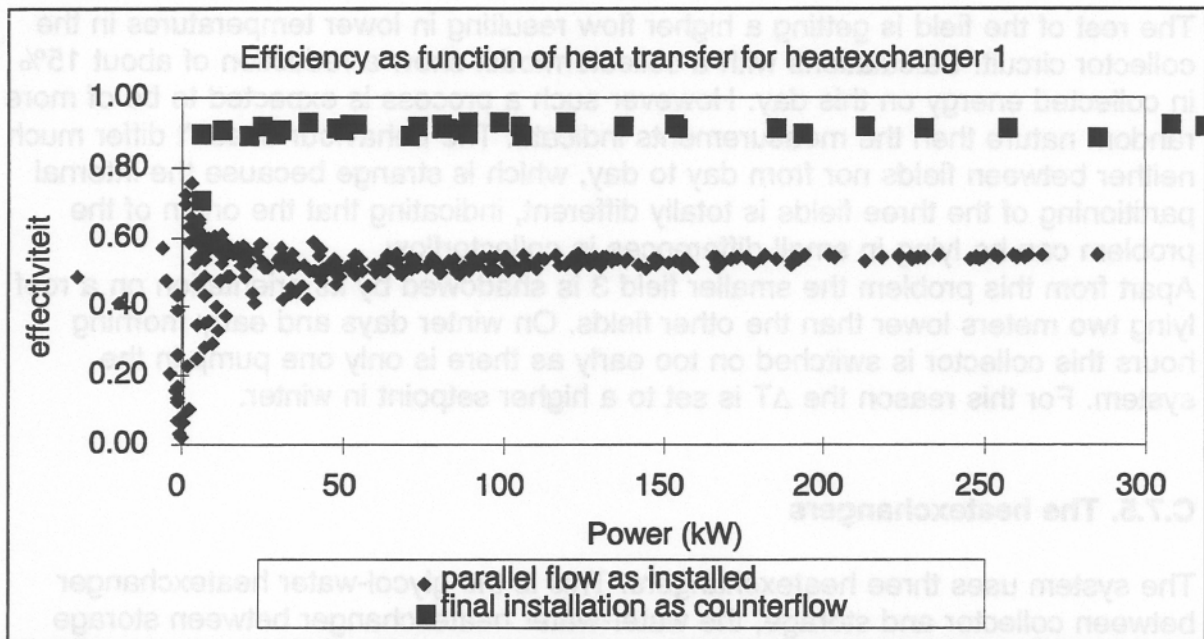
Efficiency as function of heat transfer for heatexchanger 1

Fig. C.25   Heatexchanger A; (WWA) efficiency as function of power.

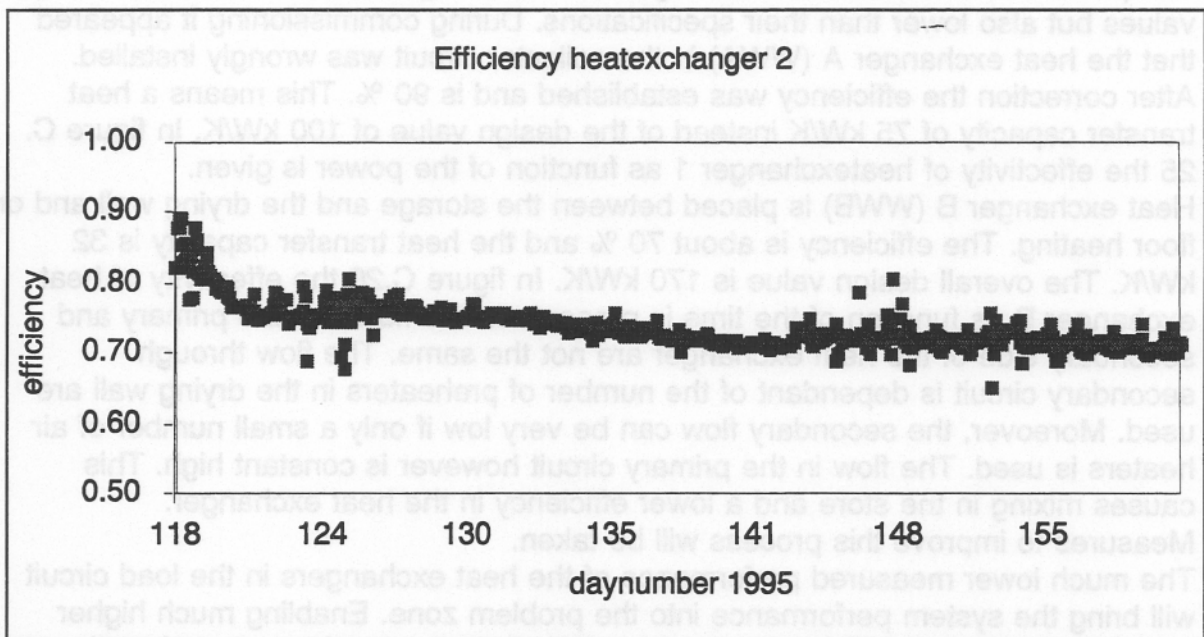Efficiency heatexchanger 2

Fig. C.26   Heatexchanger B (WWB); efficiency as time of the year.

There is a considerable difference between the design value and actual measured value for the load circuit. The higher load return temperatures also prohibit the build up of a stratified storage which in turn prevents the availability of higher store temperatures in the bulb drying process. It is expected that there will be a serious limitation in the system performance if this performance of the heat exchangers in the load is not changed. In table C.6 the design, specified and measured heat transfer values of the several heatexchangers are given.

heatexchanging capacities	design kW/m²K	specs kW/m²K	measured kW/m²K
collector circuit (glycol-water)	100	110	70
load circuit (water-water)	170	59	30
drying wall (water-air)	17	9.5	3-5

Table C.6   Overview of the heat transfer capacity of the various heatexchangers according to the design study, real specifications and actual measured value.

Drying wall

As mentioned before the drying and conditioning process of the bulbs is the critical factor. Therefore the owner controls the temperature, airflows, durations etc. of the drying process very closely. During the years the control strategy changes due to improved insights. Since the solar system and the drying wall are controlled by the same computer, the control strategy is more complex then originally foreseen. Moreover, this integration offers much more possibilities for controlling the drying process but also the heat delivered by the solar system.
The drying process is now controlled by a temperature sensor placed in a bulb in one of the drying boxes filled with bulbs. Main criterium is that the temperature of the bulbs and therefore the air temperature should never exceed the 35 °C.
The drying wall has five segments, where in front boxes with bulbs can be placed. The number of segment used depends on the number of bulbs to be dried.
Analysis of the use of the drying wall showed that the heat transfer capacity is only 20% of the design value, partly caused by the control strategy.
This lower value causes higher return temperatures in the solar circuit. This means that less energy from the store is used than possible. Improvement of the control strategy and heatexchangers capacity can improve the solar contribution to the drying process.

C.8   EVALUATION

C.8.1 Performance

The measured system efficiency is only 14% whereas 42% was the design value. During the first year of full operation several problems came to light which will need actions to be taken to get the system performance to the required level of operation. Some of these problems such as the settings of the pressure control equipment in the collector circuit belong to normal working maintenance. The repairing of the roof insulation in the storage tank is a task to be undertaken in winter as temperatures in the store are still low enough to enable entrance for human beings. Entrance could be possible via the inspection hole and inspection and reparations are perhaps possible by using an inflatable raft.
A serious limitation exist in the load heatexchangers when full performance of the drying wall will be required. Due to the much lower energy request in 1995 this has not formed a problem. However, it will do so when expansion of the firm takes place or when the climate is less favourite. The performance of the load circuit needs attention by fine tuning the circuits to get the available heat exchanger to work according specifications. A recalculation of the performance with the final equipment specifications will have to be done in order to judge the system against the original calculations.
The pump energy required to operate the floorheater amounts to the same level as the energy drawn off the store. Reconsideration of the connections and use of pump P7 for operation of this floorcircuit makes sense.
The operation of the pumps in the store discharge circuit are still giving start-up problems due to air collected in the pump. A small pump cellar below floor level in the strip area between store and former outer wall of the building but inside the new building will effectively solve these problems as all pumps can then be mounted below water level in the store.

C.8.2 Construction

Collector System
Leakages in the collector circuit were detected. This delayed the process of filling the circuit with anti-freeze. Leakages with anti-freeze are very costly. In case of too high temperatures at the pressure valve, the installation will blow off the collector fluid. This is critical for the place in the collector circuit. Moreover due to the cost of anti-freeze a drain back system filled with water is a better solution. The know-how is available in The Netherlands, the challenge is to apply this technique to large systems. A large drain back system (2400 m^2) will be constructed in 1996.

Storage
The unique construction of a storage under the requirements of the project has proven to be extremely difficult and not without technical risks. This project has learned a number of valuable lessons in creating this type of storages under ground water level.

To summarize these lessons:
1.   A storage, constructed under groundwater level should not be part of a foundation of an other building.
2.   A steel boxing construction is a cheap and practical approach to create a water tight basis for the mounting of the insulation material.
3.   A pressure relief valve in the bottom of the storage is needed in order to make sure that the storage will never start floating.
4.   The use of HDPE-foils for 100% water tight constructions is not recommended.
5.   Foam-glass insulation material can not be applied under water with temperatures exceeding 70°C because of etching the glass-wall of the foam-glass cells. Eventually this could lead to breaking of the cell-wall. The PC-88 coating applied on the foam-glass is a safe protection to this etching effect.

C.8.3 Monitoring

The monitoring system proved to be every helpful in the fine-tuning and commissioning of the system. Detailed measurements are necessary in order to detect flaws in the components, the control system are the strategy. This is of course valid for new types of systems. In the case of more experience one could decide to have monitoring based on daily or weekly values.

C.8.4 Design

The original design of the solar system for drying bulbs was changed during the realisation. In fact, this is not a strange observation but reality. From the initial project start in 1990 and the final realisation end of 1994 a number of thinks changed. The most critical part of this project occurred at the moment the system lay-out of the feasibility study was used for the final design.
Practical verification should have given much more information for the final design stage. At this moment the construction of the storage should be looked into much more detail. Even detailed studies on some aspect should have been carried out, as practice learns later in the project realisation.
After the first full year results the question is if the heat demand is lower due to the good weather conditions in 1995 or to changes in the drying process, the control strategy, the bulbs etc. Further analysis will give more information into this.
At this moment the conclusion for the design is that based on the given boundary condition of the process, the future expansion the system concept is good. The most critical factor is the long term storage and the heat losses. Time will show the performance and durability of this solution.

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