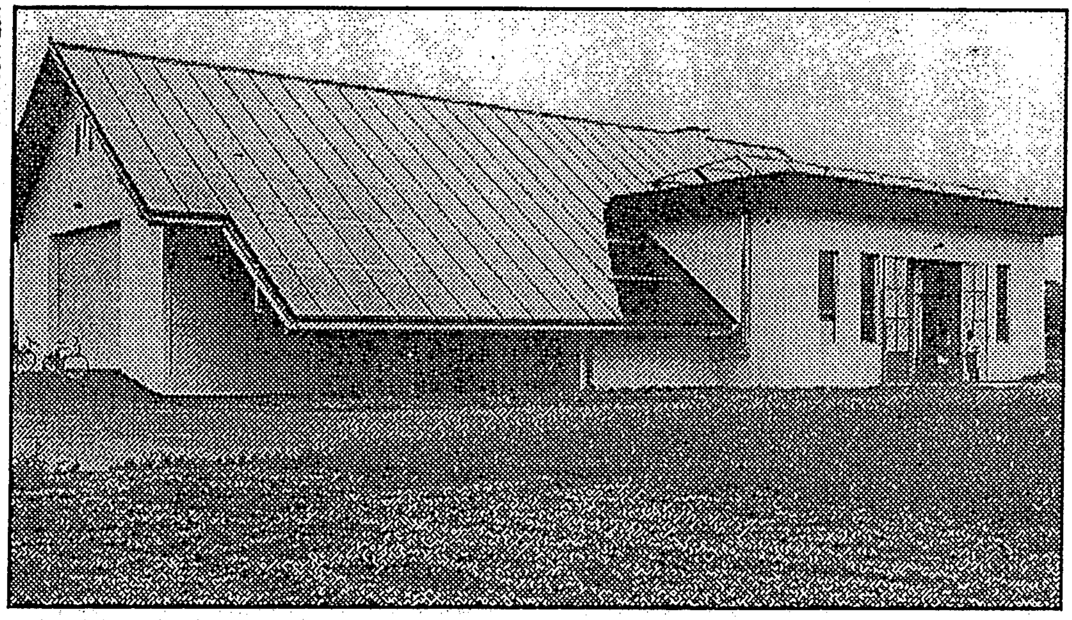
1995 Workshop on Large-Scale Solar Heating

CSHPSS Working Group, IEA SH&CP

Vienna, October 5-7, 1995



34 Haushalte werden von diesem Fernwärme-Heizwerk versorgt

"Deutsch Tschantschendorf wird für einen Tag Mittelpunkt Europas" *- Neue Kronen Zeitung*

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Appendix J

Design Study for CSHPSS with Duct Store

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DESIGN STUDY FOR CSHPSS WITH DUCT STORE

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1. Introduction

Unlike conventional technologies, the design of a solar heating system using a duct store in the ground is based on heat output (kWh) rather than heat demand (kW). It requires design procedures that account for the different thermal processes involved. It is important to assess both short-term and long-term performances. For example, the heat transfer along the ducts is influenced by different factors, such as the last days of operation of the system and the average ground temperature in the store, which normally varies on a seasonal basis. A transient effect, due to the warming of the surrounding ground, is usually observed during the first years of operation, and affects the thermal performances of the system. In order to obtain an accurate evaluation of the system heat balance, system performances have to be calculated with high resolution over several years, or even the life-time of the system. The final design is generally established with the help of detailed computer simulations, and relies on the ability of the computer programme to reproduce the actual characteristics of the planned system.

2. Objectives

Simulations of CSHPSS systems with a duct store are investigated, based on two basic system designs (i.e. with or without a short-term water buffer tank). The principal objectives are to develop reliable and accurate simulation tools, and to characterise such systems, in order to establish optimal ratios between the different subsystems' size as well as to find an optimal strategy for optimal system operation. These tasks involve:

- the set up of two systems' designs, comprising the complete system layout and connections between the different subsystems (system with and without short-term buffer tank);
- the build up of the simulation tools using TRNSYS, a well-known modular programme for the simulation of partial or complete energy systems. The world wide use of TRNSYS by researchers and consultant engineers improves the transmission of knowledge and international co-operation.
- the study of some aspects in order to check the validity of the existing modules in particular cases; finding the limitations of the simulation tools;
- improvement of the existing modules when required (e.g. the duct store module);
- having reasonably fast simulation tools for practical use (according to the system layout);
- verification with more detailed programmes; (which tend to be time consuming and not as flexible).

3. Results

Detailed programmes were developed to compute in greater detail the thermal response of a duct store coupled to a solar collector field. A reference system was defined and simulations were conducted for a typical summer month. The following analyses were carried out:

- weather data time-step effect on the simulated thermal performances of a solar plant that uses a seasonal duct storage in the ground;

- heat capacitive effects of the collector array or the ground heat exchanger on the thermal performances of the simulated system;
- the main features that a duct store model should present in order to compute with acceptable accuracy the heat transfer between the heat carrier fluid and the ground (temperature- and flow- dependent borehole thermal resistance, etc.);

The main results and conclusions related to these studies were:

- the common use of hourly rather than 2 minute weather data values results in a slight deviation in the global simulated performances. For a typical summer month (June), the cumulated energies (collected and stored) are always smaller, but the deviation is limited to 2%. It can be concluded that it is quite reasonable to use hourly meteorological data values in order to perform detailed simulations of a solar heating system using a duct store.
- heat capacitive effects of the collector array are usually small, provided that the effective heat capacity of the collector array remains below 10 kJ/m2K. Nevertheless, some simulations showed that they could be quite significant, with larger values (total collected solar heat decreased by approximately 10 % with a 30 kJ/m2K heat capacity value).
- heat capacitive effects of the ground heat exchanger, simulated for a typical summer month (June), can significantly enhance the mean collector efficiency in some extreme cases. These effects usually remain small. They can be ignored, provided that a sufficiently large buffer tank (> 60 litres/m^2 of collector area) and/or an efficient collector array are used (collector loss coefficient of 3-4 W/m^2K at high temperature).
- the local solutions, accounting for the heat transfer between the heat carrier fluid and the duct store, require special care when computed. In order to perform accurate simulations and proper sensitivity analyses, the fluid-to-ground thermal resistance should depend on the flow conditions. The axial effects, due to a varying fluid temperature along the flow channels, are accounted for with the concept of effective fluid-to-ground thermal resistance. This latter, derived from a uniform heat flux along the borehole, enables us to closely reproduce the results obtained with a detailed computation of the heat transfers inside the ground heat exchanger. Furthermore, the local solutions should be able to take into consideration a serial connection of the boreholes, as well as a vertical division of the store volume.

The detailed programmes were used to build up and validate simulation tools developed with TRNSYS. The version of the duct heat storage model (DST) for TRNSYS is improved, based on the results of analyses performed with detailed programmes. The new improvements permit a study of special problems, such as the radial stratification of the ground temperatures within the store volume, the effect of the flow conditions on the thermal performances of the system, or the effect of the heat exchange between the ducts in the borehole.

References

1. D. Pahud, Development of System Simulation Tools of Central Solar Heating Plants with a Seasonal Duct Store in the Ground, Department of Mathematical Physics, University of Lund, Sweden (1995).

2. G. Hellström*), L. Mazzarella**) and D. Pahud*), Duct Ground Heat Storage Model. Lund - DST. TRNSYS Version October 1995, *)Department of Mathematical Physics, University of Lund, Sweden. **) ITW, Universität Stuttgart, Germany, Dipartimento di Energetica, Politechnico di Milano, Italy (1995).

System design without buffer tank:

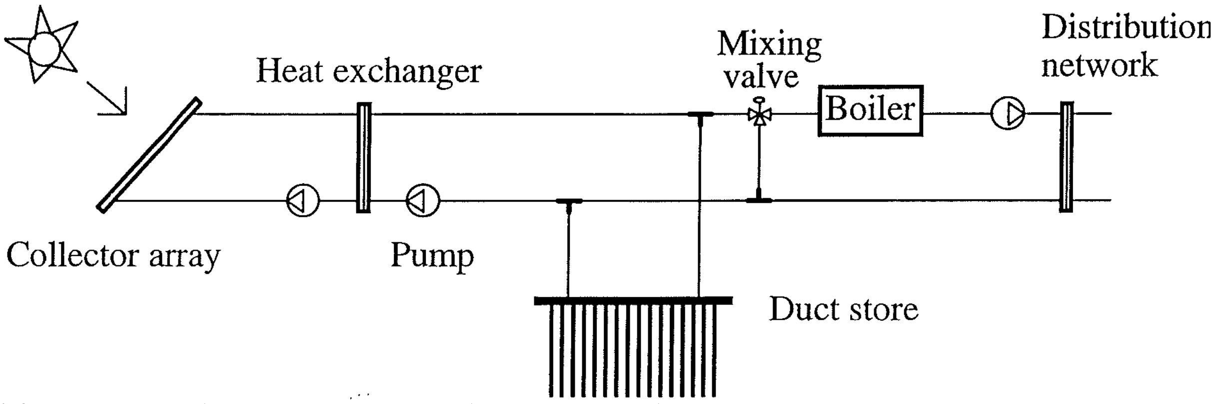

Fig. 1 Design of the system without buffer tank.

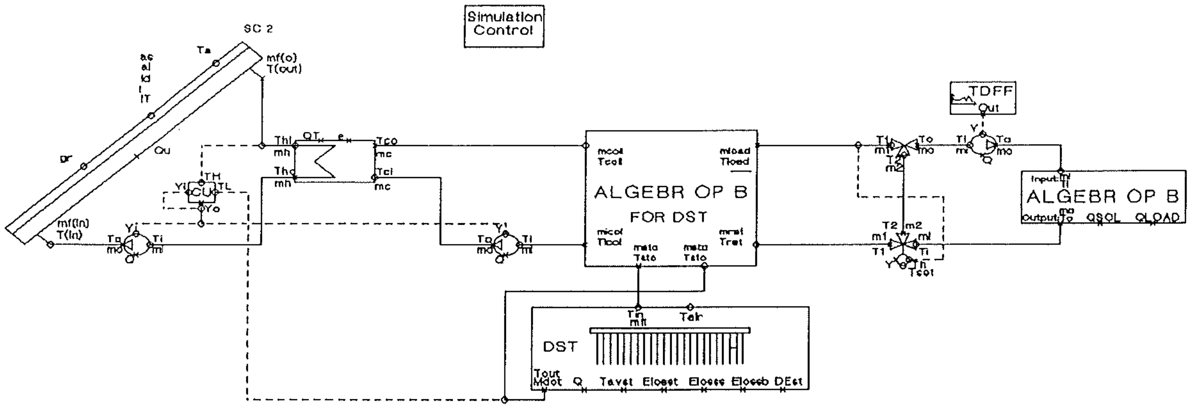

Fig. 2 PRESIM representation of the system without buffer tank.

System design with buffer tank:

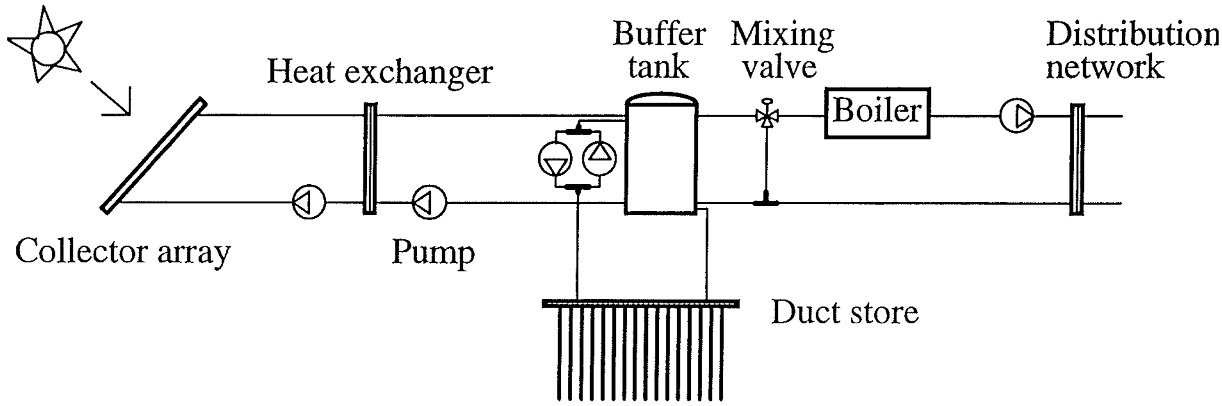

Fig. 3 Design of the system with buffer tank.

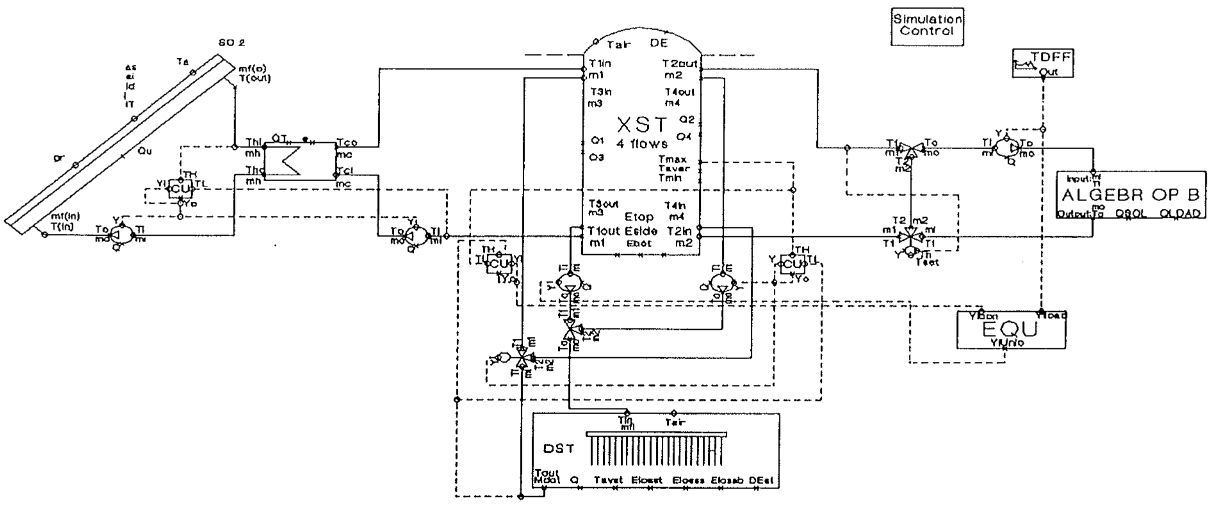

Fig. 4 PRESIM representation of the system with buffer tank.

System parameters:

SOLAR COLLECTORS:	
Location:	latitude: 59.2° North
	longitude: 17.4° East
Orientation:	azimuth: 0° (South facing)
	tilt angle (with respect to horizontal plane): 38°
Area:	35'000 m^2
Specific flow rate:	0.007 kg/sec /m^2 of collector area (loading flow rate)
Heat carrier fluid:	water
Average transmittance-absorptance product:	0.75 (-) (corrected by the collector efficiency factor F')
Overall loss coefficient:	3.5 W/m^2K (corrected by the collector efficiency factor F')
Collector heat capacity:	10 kJ/m^2K
Incidence angle modifier:	0.1 (parameter bo in $1 - bo\,(1/\cos\theta - 1)$)
Solar controller:	dead-band temperature differences: 2 - 14 K

SOLAR HEAT EXCHANGER (counter flow)	
UA_value:	120 W/K /m^2 of collector area
Specific flow rate secondary side:	0.007 kg/sec /m^2 of collector area (loading flow rate)

DUCT HEAT STORAGE	
Volume:	350'000 m^3
Depth:	125 m
Number of boreholes:	359 (spacing: 3m)
Insulation:	on top
Ground heat exchanger:	
	heat carrier fluid: water
	open annular duct, hexagonal pattern
	borehole diameter: 0.115 m
	borehole thermal resistance: 0.01 K/(W/m)
Rock:	thermal conductivity: 3.5 W/mK
	volumetric heat capacity: 2.2 MJ/m^3K
Initial store and ground temperature:	10 °C

SHORT-TERM BUFFER TANK (if present in the system)	
Volume:	5'000 m^3, insulated
Vertical extension:	10 m

HEAT LOAD		
Domestic hot water (including heat losses):	3'900 MWh/year	(30%)
Space heating requirement:	8'700 MWh/year	(70%)
Annual heat load:	12'600 MWh/year	(100%)
Forward temperature:	55 °C	
Return temperature:	30 °C	

Table 1 Parameters defining the TRNSYS systems based on the reference system.

Simulation examples, system with and without short-term buffer tank:

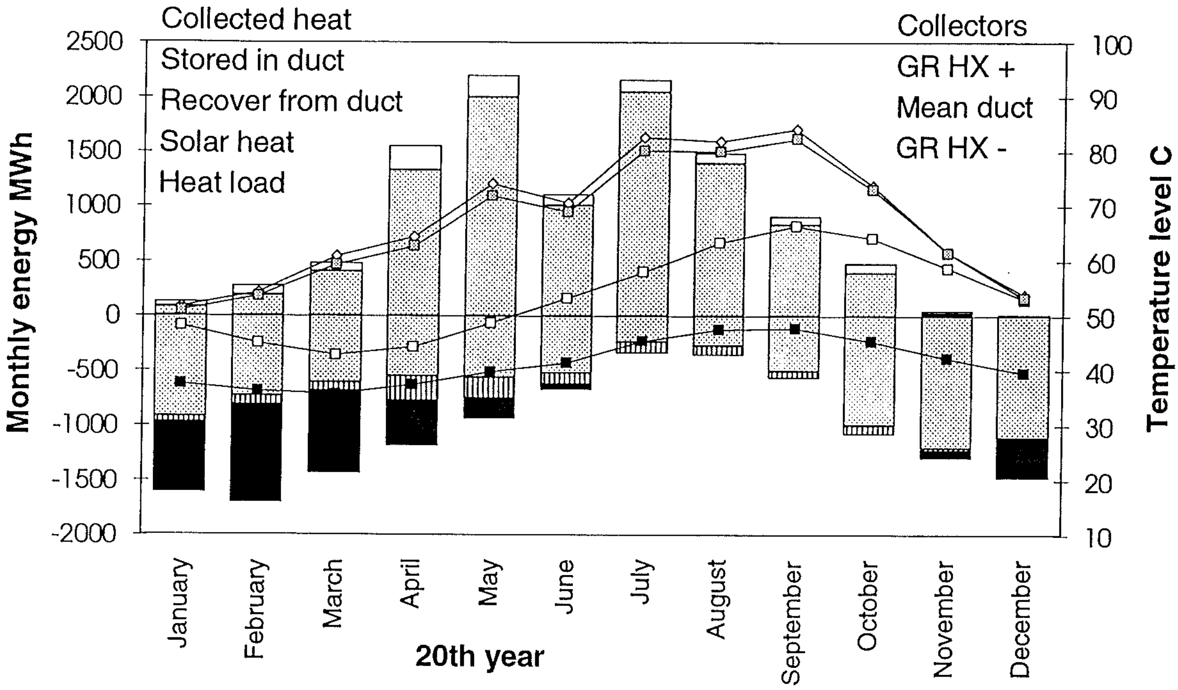

Fig. 5 Monthly heat balance simulated for the system without buffer tank. The positive energy columns represent the collected heat and the negative columns the heat load. The difference between the collected heat and the stored heat in the duct store, is the solar heat that directly feeds the heat load. The total solar heat comprises this contribution and the recovered energy from the duct store. The temperature levels in the collector array, the ground heat exchanger during heat injection, the duct store, as well as the ground heat exchanger during heat abstraction, are shown respectively from top to bottom.

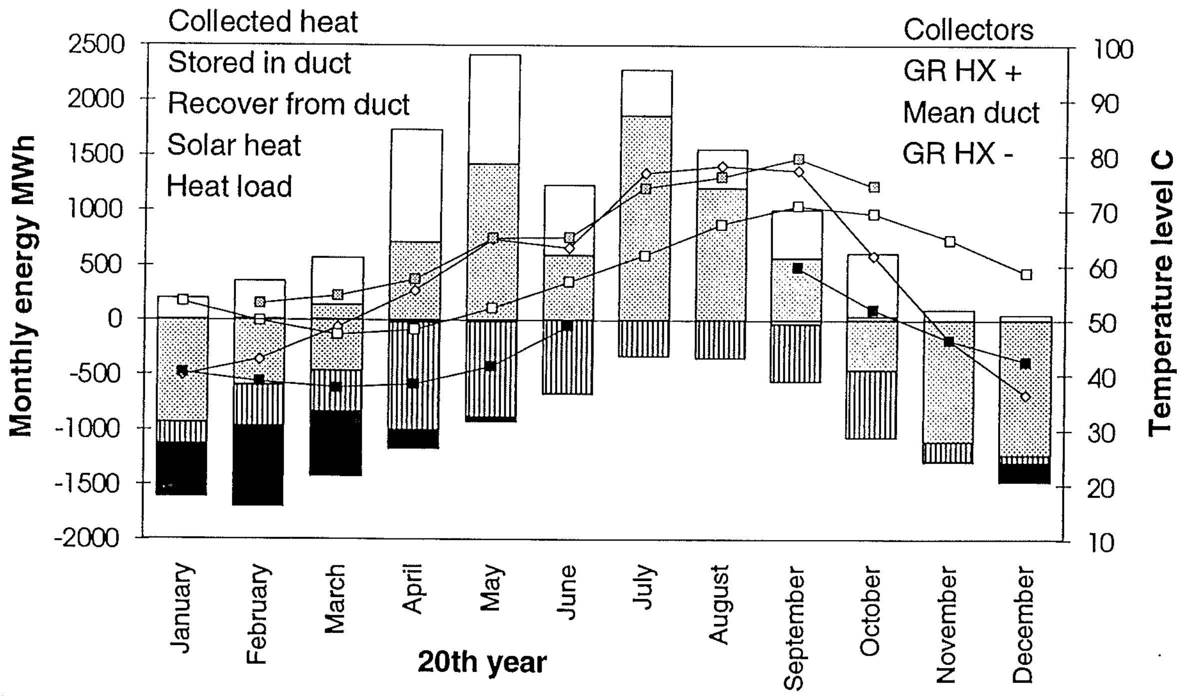

Fig. 6 Monthly heat balance simulated for the system with buffer tank. Same legend as for fig. 5 , but this time the difference between the collected heat and the stored heat in the duct store also includes the short-term heat storages in the buffer tank. The same temperature levels as in figure 5 are shown with the same labels.

Simulation examples, heat capacitive effects of the collector array:

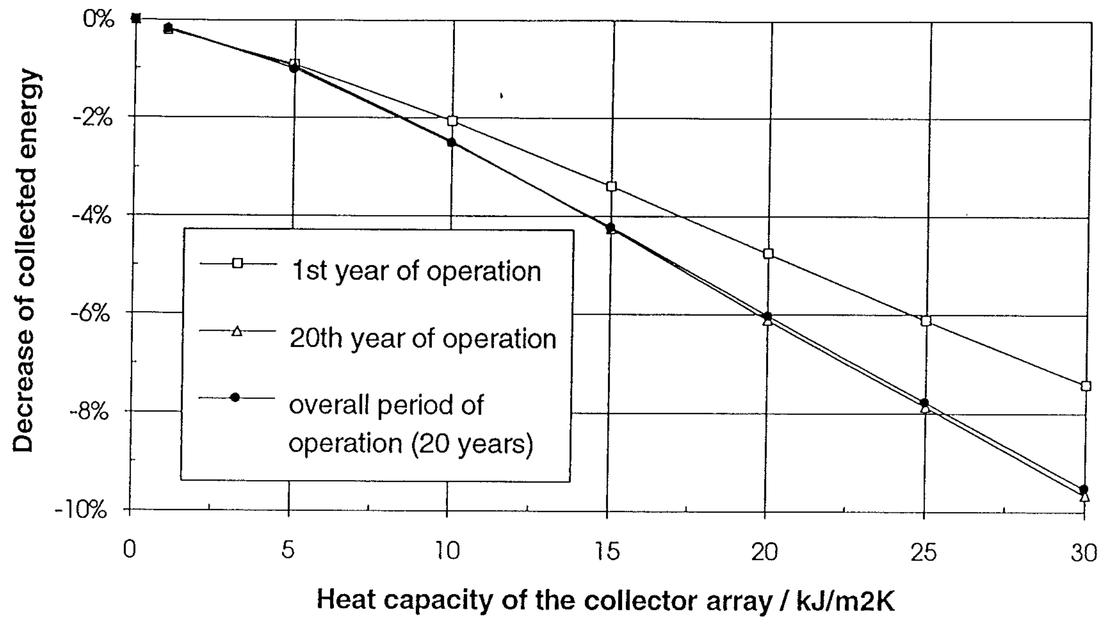

Fig. 7 Reduction of the annual collected energy in relation to the heat capacity that characterises the collector array. The simulations were performed with the reference system without buffer tank.

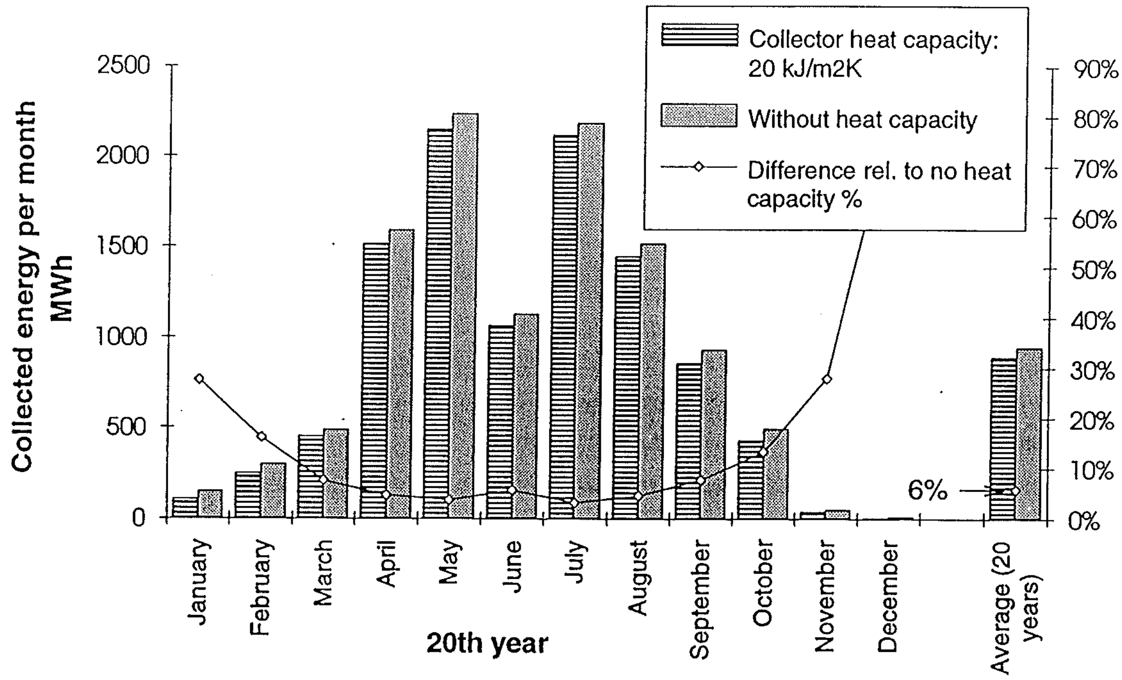

Fig. 8 Example of the heat capacitive effects on the monthly collected energy, simulated with the reference system without buffer tank.