Proc. EuroSun '96, Freiburg (DE), 16. - 19.9.1996, Vol. 1, pp. 405-409

Solar Hot Water Systems for Public Outdoor Swimming-Pools

Klaus Vajen, Frank Hilmer
Universität Marburg, FB Physik, D-35032 Marburg
Phone +49-6421/284131, Fax /286535, e-mail: solar@physik.uni-marburg.de

Abstract

Over a period of two seasons the hot water consumption, most of it for showers, and various meteorological quantities were measured minutely in the Marburg outdoor swimming-pool (about 100000 visitors/a). With the load demand profile TRNSYS-calculations were carried out, which delivered criteria for dimensioning solar hot water systems in public outdoor swimming-pools.

Introduction

In public outdoor swimming-pools uncovered absorber systems for pool water warming are spread widely meanwhile. They are economically interesting because of their simple construction and the seasonal correspondence of solar insolation and heat demand. The last point also meets for solar hot water systems for shower water heating. Furthermore, two more favourable correlations appear: firstly, a strong correlation between the course of hot water consumption and solar insolation during the day. Secondly, also the daily sums of demand and insolation are correlated slightly (see Fig.1 below). For this reason particularly favourable system configurations can be chosen. On the other hand: simulations with a mean daily demand or a consumption correlated with the daily number of visitors will fail. Only simultaneously measured data of at least hot water consumption and solar insolation can lead to proper results.

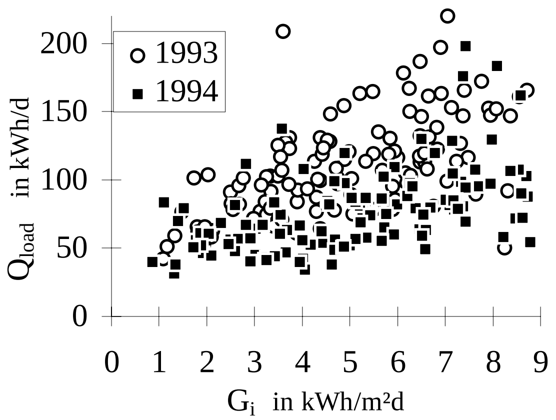

Fig.1: Daily sums of the supplied energy for hot water consumption Q_{load} versus the insolation on a tilted surface G_i (oriented to south, 20° inclination), measured at the public outdoor swimming-pool in Marburg (Germany)

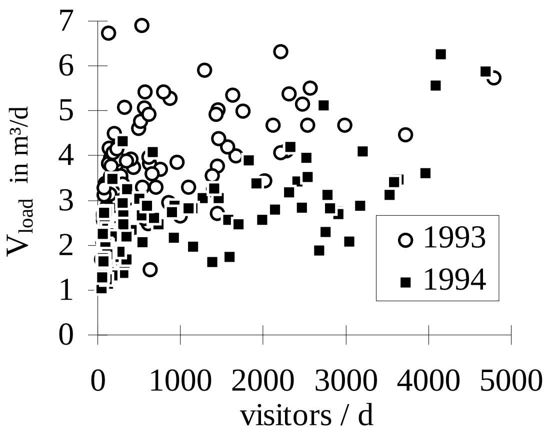

Fig.2: Daily sums of the supplied hot water volume V_{load} (40°C) versus the number of visitors. Surprisingly, both quantities are nearly uncorrelated.

Measurements

From the middle of May to the middle of September in the years 1993 and 1994 the hot water consumption, most of it for showers, various meteorological quantities and the cold water inlet temperature were measured minutely in the Marburg outdoor swimming-pool. The number of visitors was counted daily.

		1993	1994	mean	remarks
pool area	m²	1050			swimmers' pool
	m²	590			non-swimmers' pool
number of visitors	$season^{-1}$	76209	120906	98558	long-term mean value:
	d^{-1}	615	952	783	about 100000 $season^{-1}$
days of operation	d/a	124	127		sum: 251
time of operation	h	8.00 .. 19.30			summer time
collected shower-coins	$season^{-1}$	5658	4164	4911	long-term mean value:
	d^{-1}	45.6	32.8	39.1	about 4600 $season^{-1}$
visitors who had a warm shower	%	7.42	3.44		shower-coins/100 visit.
price per shower	DM	0.50	1.00		5 min
global horizontal insolation	kWh/m²season	593.3	602.3	597.8	
	kWh/m²d	5.03	5.10	5.07	
insolation on a south-oriented	kWh/m²season	618.7	628.9	623.8	calculated according to
surface, inclination 20°	kWh/m²d	5.24	5.33	5.29	/Hay80/
mean air temperature 8^{00}-19^{00} h	°C	18.6	19.7	19.2	
total hot water consumption	m³/season	440.1	305.3	372.7	
(40°C)	m³/d	3.73	2.59	3.16	
consumption for showers	%	82	73	77	
maximum consumption	$l_{40°}$/min	70	63	67	
max. mean value over 10 min	$l_{40°}$/min	55	42	48	

Tab.1: Some important quantities and prevailing conditions. Despite an increased number of visitors the hot water consumption for showers decreased 1994. This essentially could be attributed to a price rise. All sums are converted to one season (15.5.-15.9., 124 days/a).

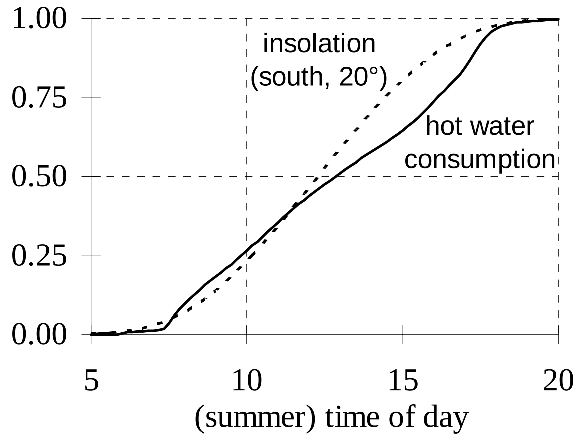

Fig.3: Mean sums over the entire measurement period of the insolation on an inclined surface and the energy of hot water consumption, normalized. Despite appreciable deviations of single values from the mean value the two quantities correspond well. The hot water consumption is nearly constant over the day with a demand-peak in the late afternoon.

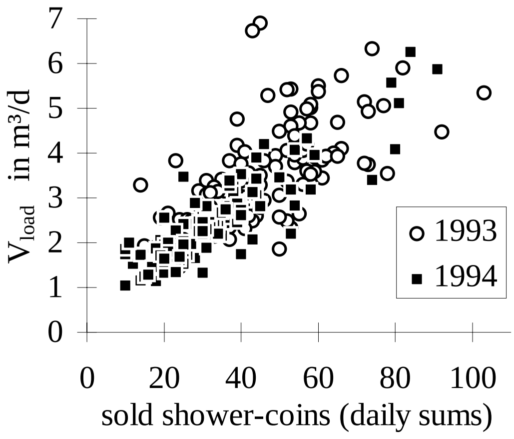

Fig.4: Daily sums of the supplied hot water volume (40°C) versus the sold shower-coins. Obviously the number of shower-coins can lead to a useful estimation of the hot water demand, if no other measured data are available.

Simulations

With the measured data TRNSYS-calculations /Kle94/ were carried out. The data of the two measurement periods were joined and the system behavior was simulated in one run with two years' data. The investigated solar system consisted of flat-plate collectors and one storage, see Fig.5 below. The german guideline /DVGW93/ to prevent water contamination with the bacterium 'Legionella pneumophila' was considered. In accordance with this guideline the entire storage was heated up to 60°C once per day.

The main focus of the investigation was laid on determination of the optimum collector-area and storage volume. The orientation of the collectors was no subject, because the operation time is almost limited to the summer. To quantify the solar economize on energy, a reference system was simulated as well, which is exclusively heated by fossil fuels.

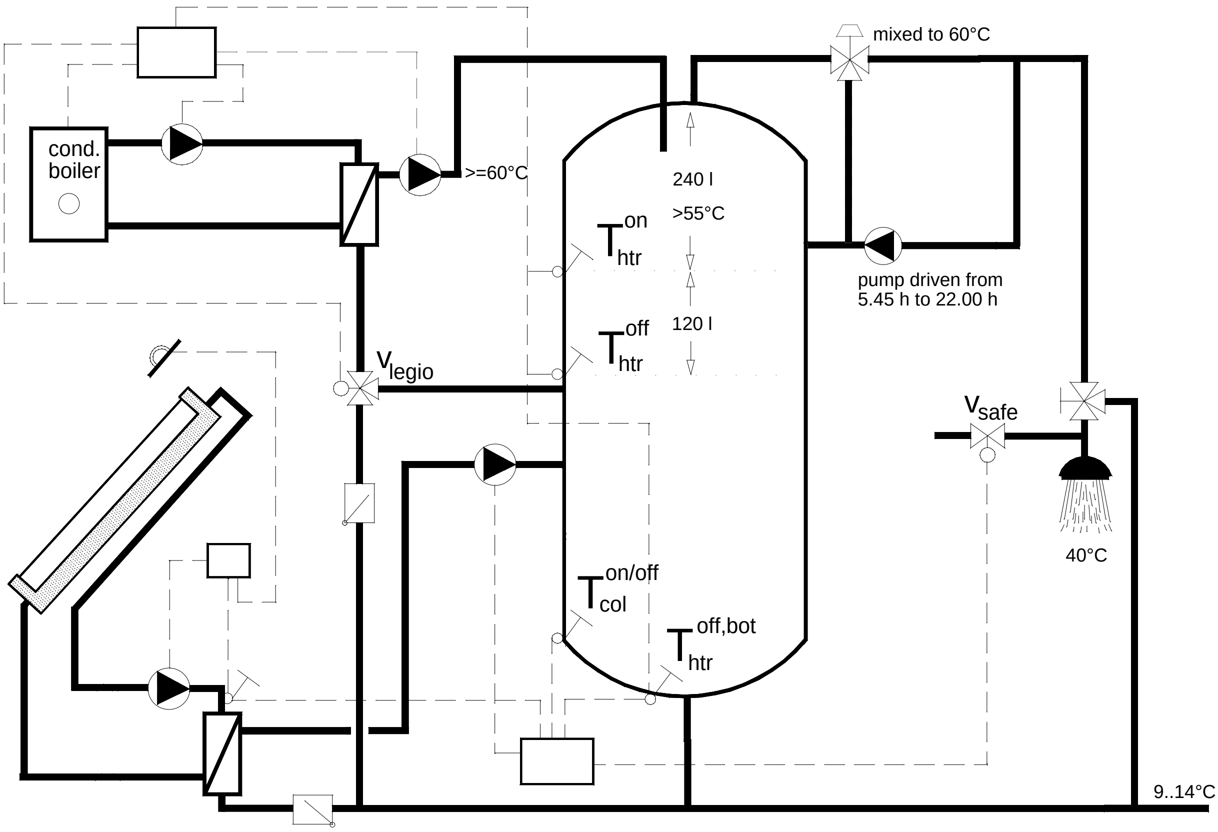

Fig.5: Hydraulic scheme of the investigated solar supported hot water system. For solar and back-up heating external heat exchangers are used either. The 50 kW condensing gas boiler is switched on if T_{htr}^{on} is below 55°C and switched off if T_{htr}^{on} is higher than 60°C and T_{htr}^{off} higher than 55°C. The water is heated up to 60°C in one run through the heat exchanger and fed into the top of the storage. Normally the water to be heated is drawn off close below the temperature-sensor T_{htr}^{off}. Once per day the valve v_{legio} is switched, so that the entire storage is heated up to 60°C. Switching the valve v_{safe} can prevent an overheating of the storage. The one-way length of the circulation pipe is 40 m. The flat-plate collector (η_0=0.78, k_1=3.5 W/m²K, k_2=0.015 W/m²K²) is high-flow driven (40 l/m²h).

Results

A comparison of solar hot water systems for outdoor swimming-pools with big SDHW-systems yields significant differences, especially concerning the optimal storage volume. In big solar domestic hot water systems most of the hot water consumption takes place in the sunless period. Although a two-storage system is more complicated in regulation and more expensive in investment, in most cases big SDHW-systems should be equipped with a small domestic-water storage and a big non-domestic-water storage, including two or more heat exchangers to charge and discharge the latter /Mah96/. Typical total storage volumes are in the range of 50 to 100 l/m² aperture area or about one daily hot water demand.

Because of the good correlation between hot water consumption and sunshine during the day (see Fig.3) a solar hot water system for outdoor swimming-pools can be carried out with only one, rather small, domestic water storage. Nevertheless solar fractions of about 50% are achievable without using the safety-cooling device v_{safe} extensively.

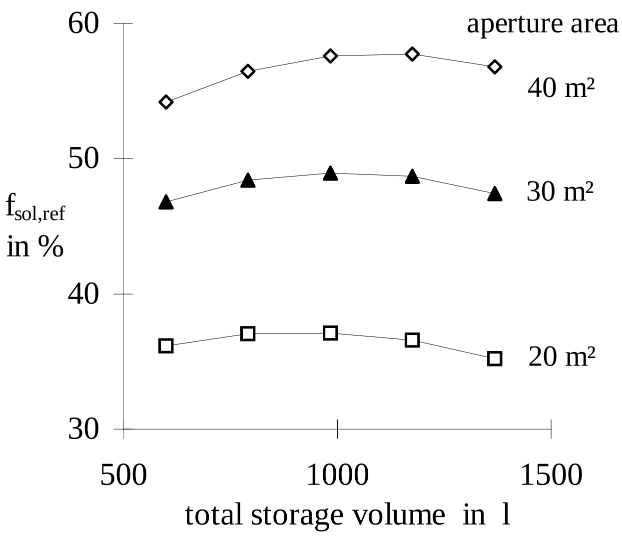

Fig.6: Solar fraction versus the total storage volume for different flat-plate collector areas, simulation results for the measured load profile. The solar fraction $f_{sol,ref}$ is defined as the total fossil energy demand (including electricity for pumping) of a solar supported system, devided by the demand of an exclusively gas heated facility. Very small storages can store only little solar heated water from the irradiation maxima at late noon to the load maxima in the late afternoon. Big storages are not able to pick up some of the solar energy because the entire storage is heated up once per day. The daily heating of the entire storage to 60°C takes place at 6^{00} h. If the storage was heated at 15^{00} h, the maxima of the solar fractions could shift to higher storage volumes.

storage volume	V/A	energy demand	η_{boiler}	th. losses	th. losses	q_{sol}	Q_{cool}	$f_{sol,ref}$	$f_{sol,input}$
(total)		(fossil, th.+el.)		(circulation)	(storage)			(fossil ref.)	(/Duf91/)
l	l/m²	kWh/a	%	kWh/a	kWh/a	kWh/m²a	kWh/a	%	%
360	-	13839	101.4	1999	207		-	-	-
600	20	7420	97.2	2116	223	243	50	46.8	52.0
792	26	7199	97.4	2108	245	250	19	48.4	53.5
984	33	7124	97.6	2104	272	253	5	48.9	54.0
1176	39	7156	97.8	2107	304	253	2	48.7	53.9
1368	46	7335	98.2	2107	343	247	0	47.4	52.5

Tab.2: Some detailed results of the simulations for an exclusively gas heated (first line) and several solar supported systems (aperture area 30 m²). The total energy delivered to load was 11750 kWh/a. q_{sol} is the energy delivered to the storage by the solar system per unit aperture area. Q_{cool} is extracted from the storage by switching the security valve v_{sec} to prevent overheating if the temperature at the bottom of the storage exceeds 89°C. $f_{sol,ref}$ is correlated with the primary energy saving (see. Fig.6), $f_{sol,input}$ with the solar energy delivery to the storage (see below).

As an example some detailed results of the simulations are shown in Tab.2. The usual definition of the solar fraction $f_{sol,input}$, concerning the fossil and solar energy delivery to the storage tank /Mack96/, neglects the decrease of the efficiency of the condensing boiler due to solar preheating and the increase of thermal circulation- and storage-losses. In that way the fossil energy saving by the solar system is overestimated significantly. For this reason we recommend to compare the fossil energy demand of the solar supported system with that of an exclusively fossil heated reference system.

Conclusions

Solar hot water systems for outdoor swimming-pools should be carried out with only one rather small domestic water storage. It seems sensible to aspire to solar fractions of about 50%. Then a total storage volume of about 30 to 35 l per m² aperture area or about 25 to 30% of the daily hot water consumption (40°C) is sufficient. The installation of a cooling device to prevent overheating of the storage should be taken into consideration.

Furthermore some measures should be followed. For back-up heating with an external heat exchanger a condensing boiler should be used. Its better regulation behavior is important to prevent repeated on/off control decisions of the heater due to solar preheated water. A mixing device between the circulation forward- and back-flow leads to an increase of the solar fraction of about three percentage points. The circulation losses are reduced considerably and, since more cold water flows into the storage, the solar delivery to the storage increases. The daily heating of the entire storage should take place in the early afternoon, when the storage is solar preheated maximally, instead of the morning. Replacing the flat-plate collectors by vacuum-tubes the aperture area could be decreased by 10 to 15% at the same solar fraction.

The usual definition of the solar fraction, which takes into account only the fossil and solar heat delivery to the storage(s), doesn't describe the fossil energy saving by the solar system correctly. It will be overestimated significantly, especially when a condensing boiler is used and/or when the ratio of storage volume to collector area is small.

Transferability

The demand profile dynamic in other typical public outdoor swimming-pools, where a little fee is taken for a warm shower, should be similar to the measured one. The yearly sums of hot water consumption agree with the results of an evaluation of about 50 pools in Hessen (Germany) /HMUEB94/. Based on the results described above, with the seasonal sums of the insolation and of the sold shower-coins a proper dimensioning of a solar hot water system should be possible.

Rough evaluations of the hot water consumption in three other german public outdoor swimming-pools with warm showers free of charge indicate, that the total hot water consumption per visitor is about four times higher in this case. The authors recommend to choose a similar system configuration as described in this paper, although the details of dimensioning should be based on measurements of the consumption.

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Acknowledgements

Special thanks to H.Ackermann (FB Physik, Univ. Marburg) and R.Orths (Wagner Solartechnik, Cölbe) for many stimulating and fruitful discussions and to H.Drück (ITW Stuttgart) for his support to a proper use of the Type74 storage model.