A Solar Installation for Industrial Hot Water

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ABSTRACT

This study includes the results of an investigation on the performance of the solar hot water system which has been installed at the Changi International Airport Services, Singapore. The Catering Services require about 50 m^3 of hot water per day at a temperature of 70°C for cooking purposes and washing utensils. The hot water is supplied by a solar installation which uses about 630 m^2 area of solar collectors with a storage capacity of 40 m^3 in four tanks. The system has been fully instrumented and is controlled by an automatic controller. A computer program has been developed to evaluate the performance of the system. The measured performance indicates a solar fraction of 0.60, which agrees fairly well with the predicted values.

INTRODUCTION

The higher prices of fossil fuels and the gradual depletion of these finite resources have provided an impetus for the conservation of energy. Considerable efforts have been made to identify alternative sources of energy in order to reduce the heavy demand on conventional fuels. The use of solar energy for low temperature applications, such as industrial process heating and hot water supply, has been receiving considerable attention in recent years as a potential means of supplying thermal energy at a reasonably low cost. The geographical and meteorological conditions of Singapore are favourable for such applications, particularly the supply of hot water in the temperature range of 60 to 80°C. In this study, a large industrial solar hot water system at the Changi International Airport Services (CIAS), Singapore, is described.

THE SYSTEM

The flight kitchen, which caters for many of the airlines at the Changi International Airport, requires large quantities of hot water at a temperature in the range of 60 to 80°C for cooking purposes and for washing utensils. The hot water is obtained from a solar installation, shown schematically in Fig. 1. The solar energy is collected by solar panels, having an area of about 630 m^2. This energy is stored in four storage tanks, each having a capacity of 10 m^3. The design of the tanks allows thermal stratification to be established in it. An auxiliary boiler maintains the desired temperature when the supply of solar energy is inadequate. The system has been fully instrumented and an automatic controller is employed to control the operations. The daily demand for hot water varies between 45 and 55 m^3, and between 10:00 p.m. and 7:00 a.m. hot water is hardly used at all.

OPERATION OF THE SYSTEM

The basic components of the solar hot water system are flat plate collectors, heat exchangers, storage tanks, an auxiliary heating unit, and an air cooler. The components are connected by a network of well-insulated pipes to prevent heat losses. The system has a rated capacity for producing 60 m^3 of hot water at a temperature of 70°C under fairly good meteorological conditions. In the design of the system, provision has been made for future expansion in order to increase the total collector area to 1200 m^2.

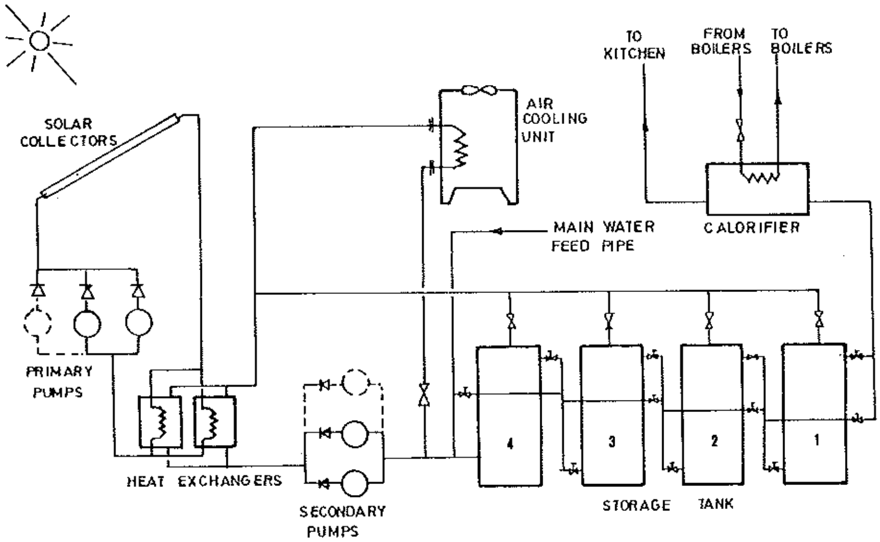

Fig. 1 Simplified diagram of the industrial solar hot water system at CIAS

The solar installation, shown in Fig. 1, has basically two circuits in operation: the primary circuit and the secondary circuit.

The Primary Circuit

This circuit operates in a closed loop and consists of the collectors, heat exchangers and circulation pumps. The solar system uses 321 Yazaki blue panels, providing an effective area of about 630 m^2. To comply with health safety regulations, the primary circuit is isolated from the secondary circuit by means of heat exchangers. Water is used as the heat transfer fluid in the collector loop. The solar energy incident on the collectors and absorbed by water circulating through collector tubes is transferred via heat exchangers to the fluid circulating in the secondary circuit. When the exit temperature of the solar collector is higher than that of water at the primary pump outlet, the pumps circulate water through the collectors to transport energy from the collector to the heat exchanger.

The Secondary Circuit

This circuit operates in an open loop and consists of storage tanks, an auxiliary heater, an air-cooler unit, and circulation pumps. When the temperature of the water at the collector exit is higher than that of the water in any of the four storage tanks, the secondary pump is activated. The energy transfer to the storage tanks takes place beginning with storage tank 1. When there is a demand, hot water is tapped from tank 1 at the top and an equal amount of cold water is delivered from the main water feed pipe to the bottom section of tank 4. If the temperature of water leaving tank 1 is less than the desired value, the auxiliary unit will operate automatically to raise the water temperature sufficiently. This auxiliary energy is supplied by gas fired boilers.

When all the storage tanks have reached the temperature limit, and if the collector exit temperature is 85°C, the water in the secondary circuit is circulated automatically through the air cooler unit to dissipate excess energy into the atmosphere.

SIMULATION METHODOLOGY

The performance study of the system requires the following three distinct pieces of information:

i) the meteorological conditions of the site,

ii) the pattern of hot water demand,

iii) mathematical equations, describing the performance of the different components of the system.

The meteorological office in Singapore measures hourly values of global radiation, wind speed and ambient temperature along with other data at a location near Changi International Airport (01°22 'N, 103°55 'E). Table 1 shows the daily global irradiation on a horizontal surface for a typical year. There is also negligible annual variation of solar radiation, as shown by Hawlader.[1] This indicates that there is no appreciable seasonal variation of the available solar energy. The performance study also requires the hourly values of direct and diffuse components of the global radiation, which the Meteorological station does not measure. The components of the global radiation were obtained by using the method described by Hawlader.[2] These data were used for the evaluation of useful energy gained by the solar collectors.

The Changi International Airport Services (CIAS) in Singapore operates in three shifts, and the hourly hot water requirement for a typical day, is shown in Fig. 2. The total hot water demand for the day is about 52 m^3, at a temperature of 70°C. This distribution of load was used in the simulation study. The different components of the system have been represented by equations described in references.[3, 4]

RESULTS

The computer program developed for the performance study of the CIAS system was run with the hourly meteorological data of the site. Although the system is controlled by an automa-

Table 1
Daily total global irradiation for the year 1978, MJ/m^2

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	14.9	21.5	9.6	19.7	17.4	19.2	12.1	16.7	13.5	17.3	15.3	12.4
2	20.2	18.7	18.4	24.1	13.4	20.8	19.2	18.3	14.6	19.7	13.8	5.8
3	23.9	19.5	16.5	24.3	16.8	15.5	5.3	15.1	7.5	17.1	4.7	6.4
4	16.1	17.8	20.2	15.6	14.4	19.2	10.6	15.4	13.4	19.7	17.4	18.8
5	17.2	11.6	21.1	13.1	12.2	11.0	16.3	10.4	14.7	14.3	9.9	16.4
6	5.1	16.7	16.5	13.7	11.1	6.4	17.7	10.9	6.7	17.3	12.1	16.1
7	17.5	22.4	18.4	15.1	12.6	10.7	12.9	15.4	18.4	13.9	16.0	18.0
8	0.6	20.5	20.9	19.0	19.6	15.3	12.1	15.1	8.8	10.5	12.8	21.3
9	9.2	20.6	15.2	16.5	10.0	11.5	17.9	19.8	12.6	18.0	8.2	9.9
10	1.7	19.4	14.6	22.7	9.7	8.7	12.0	18.3	13.7	15.6	10.0	12.3
11	5.1	21.1	19.2	18.3	17.7	16.2	6.8	16.7	11.7	13.0	11.0	13.4
12	11.9	19.8	24.1	14.8	13.7	15.9	13.3	8.4	14.4	14.1	11.5	16.4
13	15.2	21.3	13.8	18.8	12.9	18.1	10.3	12.1	7.3	10.6	8.4	16.1
14	19.5	20.7	12.1	10.8	4.4	19.9	16.6	12.3	19.7	19.3	11.5	8.1
15	18.4	15.3	14.3	12.5	11.5	19.7	18.5	6.5	16.5	9.1	8.3	18.9
16	17.1	17.6	18.3	20.0	14.1	8.4	17.6	15.5	9.2	9.9	7.6	12.0
17	9.3	15.4	20.3	15.3	13.1	17.8	18.3	12.3	17.9	9.8	16.2	17.3
18	16.7	8.9	13.7	15.2	7.4	10.7	17.8	18.3	22.6	18.7	8.6	19.7
19	21.3	8.5	9.0	13.4	10.4	14.7	16.9	13.6	21.9	15.8	18.7	13.4
20	19.1	21.2	19.0	16.9	16.8	6.0	18.3	18.3	15.2	13.7	11.9	9.5
21	19.8	19.8	12.2	17.5	14.8	20.0	16.8	8.6	18.6	14.9	15.1	15.6
22	18.0	21.4	9.7	8.2	15.2	20.3	17.8	18.2	16.5	16.3	13.7	1.4
23	12.5	23.6	21.5	17.7	12.8	16.3	16.9	15.0	17.1	15.1	6.4	12.5
24	12.3	19.7	21.3	16.4	18.5	9.2	10.1	18.7	18.4	11.4	16.9	11.3
25	17.1	21.3	20.8	15.3	19.1	8.9	13.8	18.6	9.2	10.3	11.0	19.1
26	13.6	8.5	12.2	17.0	20.8	15.7	17.1	15.0	21.6	14.4	7.6	17.1
27	16.5	22.3	18.5	9.2	19.8	5.3	15.2	19.8	21.5	9.2	12.6	16.3
28	14.5	9.3	5.5	13.6	17.1	16.4	16.9	13.3	17.5	11.5	6.1	14.8
29	12.1		13.2	21.1	13.8	7.7	9.1	10.9	12.3	10.6	19.2	20.0
30	21.0		16.6	20.0	17.3	14.7	18.0	19.0	20.5	8.4	19.7	16.1
31	19.5		13.1		4.4		15.9	16.8		5.6		18.9
TOTAL	456.2	504.4	499.8	495.8	432.8	420.2	458.1	463.3	453.5	425.1	362.2	445.3
Monthly average of daily totals	14.7	18.0	16.1	16.5	14.0	14.0	14.8	14.9	15.1	13.7	12.1	14.4

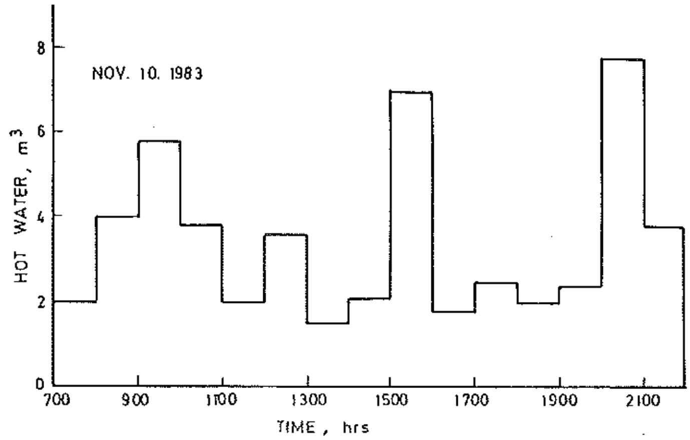

Fig. 2 Hourly distribution of hot water demand

tic controller, there is no automatic data logging system at present. Instrument readings were taken at 9:00 a.m., 1:00 p.m. and 5:00 p.m. every day and entered in a log book. Since the program requires hourly information, data were collected for two days, 10 November and 11 November 1983 on an hourly basis. Using these hourly meteorological data, the computer program was run with the system parameters shown in Table 2. Table 3 shows the measured and predicted re-

Table 2
System parameters

Collector area	:	629.16 m^2
Tilt	:	10°
Orientation	:	South/North
Collector heat loss coefficient	:	Calculated as function of wind speed
Panel absorptance	:	0.92
Glazing	:	Single
Transmittance		
at normal incidence	:	0.84
at 60° incident angle	:	0.756
Collector efficiency factor, F ′	:	0.92
Ground reflectance	:	0.05
Collector heat capacity – panel + water content	:	10,000 J/m^2 K
Collector flow rate	:	20 m^3/h
Pipe heat loss coefficient	:	0.335 W/m^2 K
Pipe heat capacity – pipe + water content	:	5,000 J/m^2 K
Heat exchanger conductance – area product	:	105235.2 W/K
Store volume – 4 stores, 10 m^3 each	:	40 m^3
Aspect ratio of store	:	1.39
Heat loss coefficient for stores	:	0.4 W/m^2 K
Supply water temperature (constant throughout the year)	:	29°C
Load demand (considered constant throughout the year)	:	52 m^3

Table 3
Daily performance of CIAS solar water heating system

Day / Variables	10 November 1983		11 November 1983	
	Measured	Predicted	Measured	Predicted
Collector Input (GJ)	9.889	9.889	7.840	7.840
Collector Output (GJ)	5.760	5.259	3.960	3.409
Collector Efficiency (%)	58.2	53.2	50.5	43.5
Storage Output (GJ)	2.520	2.804	2.520	2.138
Demand Load (GJ)	4.734	4.734	4.342	4.342
Solar Fraction	0.53	0.59	0.58	0.49

sults for the two days. The agreement between the predicted and the measured values is fairly good, as shown in Table 3.

The simulation program was run with the same input parameters shown in Table 2 for several years, and Table 4 shows the typical results. In this study, the magnitude of the load and its distribution is assumed to be constant. The temperatures of the supply water and the load were considered constant at 29°C and 70°C respectively, although in reality the temperature of the supply water may vary with time. Even the load varies from day to day. Actual solar fraction is likely to be slightly different from the predicted fraction.

Table 4
Predicted performance of CIAS solar heating system for the year 1978

VARIABLES	MONTHS											
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Collector Input (GJ)	295.5	321.6	307.5	294.4	251.3	241.3	265.8	274.6	274.8	260.3	227.1	286.7
Collector Output (GJ)	156.0	169.4	162.3	158.9	134.5	128.2	141.4	146.1	146.4	139.1	122.1	156.2
Collector Efficiency (%)	52.8	52.7	52.8	53.9	53.5	53.1	53.2	53.2	53.3	53.4	53.7	52.4
Store Input (GJ)	155.4	168.8	161.7	158.3	134.0	127.7	140.9	145.6	145.8	138.5	121.6	149.6
Store Losses (GJ)	2.68	4.07	3.96	3.71	3.39	3.15	3.45	3.60	3.58	3.49	2.92	3.65
Demand Load (GJ)	239.8	216.6	239.8	232.1	239.8	232.1	239.8	239.8	232.1	239.8	232.1	239.8
Solar Contribution (%)	64	78	68	68	57	54	58	60	62	59	51	62

Table 5 shows the measured performance of the system for the period from January 1983 to December 1983. The fraction of the load supplied by solar energy is also included in the table. Table 5 shows a daily average hot water demand of 46.8 m^3. Solar energy supplied 58.8% of the total energy required to raise the temperature of supply water from 29°C to the desired load temperature of 70°C. The solar contribution is below 50% in the months of November and December which are usually gloomy months, as indicated by the lower levels of radiation available. When Tables 4 and 5 are compared, the predicted results are slightly higher than the measured values. This could partly be attributed to the higher value of the assumed supply water temperature of 29°C.

Table 5
Measured solar fraction of the energy required for the CIAS system for the year 1983

Month	Solar Heat Gain (GJ)	Load		Solar Fraction	Annual Average Solar Contribution
		Hot Water Consumed (m^3)	Energy Required (GJ)*		
January	119.88	1355	232.4	0.52	
February	159.12	1198	205.5	0.77	
March	159.84	1254	215.1	0.74	
April	149.40	1319	226.3	0.66	
May	145.08	1153	197.8	0.73	0.58
June	141.84	1486	254.9	0.55	
July	135.36	1605	275.3	0.49	
August	163.44	1673	287.0	0.57	
September	136.80	1489	255.4	0.53	
October	143.28	1393	238.9	0.60	
November	128.32	1635	280.5	0.45	
December	108.72	1512	254.4	0.43	

*Based on water supply temperature of 29°C and load requirements at 70°C.

Table 6
Solar contribution of the load in percent for different load temperature

Load Temperature (°C)	MONTHS												Annual Average Solar Contribution
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
70	75	77	68	54	57	51	55	64	64	60	49	66	61
65	85	88	77	62	64	58	62	72	73	68	56	75	70
60	99	102	90	72	75	67	72	84	85	75	65	88	81
55	117	122	107	85	89	80	86	100	101	94	78	104	97

Table 6 shows the influence of the temperature at which the hot water needs to be supplied on the solar contribution of the load. The solar farction of the load increases dramatically when the demand temperature is reduced.

CONCLUSIONS

The simulation study agrees well with the observed performance of the CIAS solar hot water system. The existing solar installation can provide about 60% of the total energy required at the catering facility for water heating purposes. This indicates a considerable saving on fuel bills – though the initial capital investment is high.

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