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Optimization of Solar Cooling System in Latvia

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***Abstract* – The paper presents optimization of Solar Cooling System in Latvia using the modelling of solar cooling system which was created by dynamic simulation program. The model is similar to the existing real solar cooling system in the Institute of Physical Energetics. The precision of the model was tested by comparing it with real equipment. Simulations were carried out using metrological data of different European countries. Simulation results, dependency of heat carrier average temperature and proportion of energy from pump to the system were collected and analysed. Different element location of solar cooling system was compared in two models. Annual cool production of solar cooling system was defined.**

***Keywords* – Solar energy use, solar cooling system, thermal-driven chiller.**

I. Introduction

Modelling of solar cooling system was performed by dynamic simulation program. The model is similar to the existing real solar cooling system in the Institute of Physical Energetics. The precision of the model was tested by comparing it with real equipment. In the model, the location of pumps in flow <-> out flow lines and return lines was changed.

Simulations where carried out using metrological data of different European countries. In such a way, the variation range was determined for the impact of pump placement effect on solar cooling system in different climate condition that increases the possibilities of using the model in other EU countries.

The PolySun simulation program was used for system simulations. The base model was adapted to the model with low-power heat driven adsorption cooling. Adsorption chillier nominal power is 8 kW and maximal cooling capacity is 11kW. Heat was used for thermal driving chilling; this heat was mainly derived from solar thermal system. In this case, solar thermal system with thermal power 15kW at ΔT = 70K was used [1]. One cubic meter accumulation tank with 8kW electric heater is included in the solar thermal system. Cooling system was designed in such a way as to provide about 80% of the maximal cooling power. Cold water buffer was used for peak alignment. Wet cooling tower with 21kW of nominal power was used for heat rejection. Excess heat from solar thermal system was redirected to the hot water preparation. Hot water consumption was designed according to the solar thermal system monthly maximal productivity in the non-cooling season.

II. Methods

It has been demonstrated that the most rapid development due to improvement and installation of solar cooling systems has been achieved in the European region. That is why the study mainly discusses the results of the given region. The results of different European regions were analysed through the base model simulation of the given system. After the evaluation of the obtained results, meteorological data of Spain (SR-South region) was taken as the reference location where maximum productivity is necessary. Meteorological data of Latvia (NR-North region) was chosen as the location of the minimum productivity with relative necessity for cooling.

Simulation results show that cold yield with the given solar cooling system is from 1.5 MWh/a in NR till 3.7 MWh/a in SR. Thermal driving chiller working time is from 410h/a in NR till 970h/a in SR. Cold yield of the given study includes the rejected heat from indoors. Heat rejection demand has been adapted to space-heating in a certain climate in the cooling season. The study is aimed at household and office space cooling, so the cooling demand of technical process wasn't included in this model.

The above-mentioned cold production with thermal driven chiller mainly consumes heat. The heat supplied in the generator is from 3.6MWh/a in NR till 10.3MWh/a in SR. Re-cooling heat with wet re-cooling tower is from 5.1MWh/a in NR till 14MWh/a in SR. Both water and electricity are used during wet re-cooling tower operation. Electricity was mainly consumed for fan operation amounting to 0.25MWh/a in NR till 0.6MWh/a in SR for given heat rejection. Thermal efficiency of the wet cooling tower is from 16.9% in NR till 22.6 % in SR. In its turn, for one MWh heat reject with wet cooling tower has been consumed from 0.043MWh in SR till 0.050MWh in NR of electricity for fan operation.

Solar cooling systems have six closed circuits:

- Solar collector circuit - between solar collectors and heat accumulation tank;
- Driving heat circuit – between heat accumulation tank and thermal driving chiller;
- Re-cooling circuit – between thermal driving chiller and cooling tower;
- Chilled water circuit – between thermal driving chiller and cold accumulation tank;
- Hot water circuit – between heat accumulation tank and hot water accumulation tank;
- Cooling distribution circuit.

Each circuit has its own pump, which can be separately controlled by using certain programs from a common control unit. Each pump consumes electricity and creates potential energy – pressure and kinetic energy – flow. As well, heat losses are released during pump operation. One part of the heat losses goes to the environment – mostly indoor, and the other part of heat losses is transferred to the heat carrier.

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Kinetic energy combined with heat losses to heat carrier and crate total energy to the system from pumps. Total energy input to the system is from 7 to 31% of the consumed electricity in the solar cooling loops. Given ratio is dependent on operating parameters, including the temperature of heat carrier to which that energy is transferred [2].

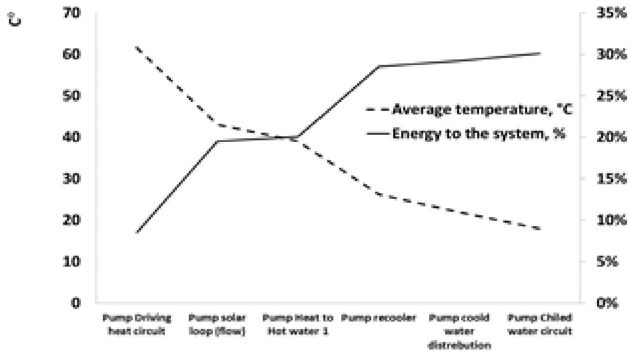
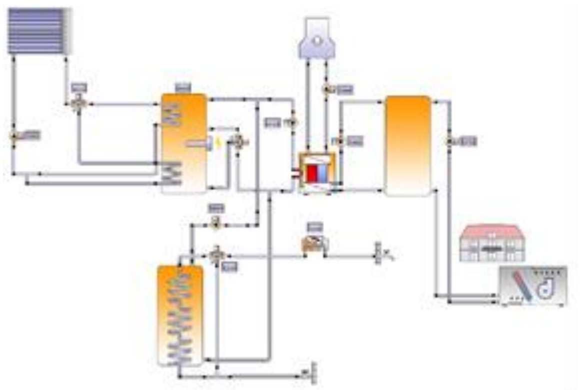


Fig.1. Dependency of heat carrier average temperature and proportion of energy from pump to the system.

As can be seen from Fig.1, the percentage of the amount of energy that is transferred to heat carrier from the consumed electricity is inversely proportional to the temperature of heat carrier which flows through the pumps. The main reason is that potential increase raises heat flow from pump components to the heat carrier. This potential is directly proportional to the temperature difference, meaning that heat flow amount increases with the decrease of heat carrier temperature at the inlet of the pump.

The yield of solar cooling elements (such as solar collector, heat-driven adsorption chiller, cooling tower and heat exchangers) depends on the intake amount of heat. Therefore, the pump location before or after the specified element of the given system affects the element yield. In the present study, location of pumps will be changed at flow return line of circuits in correcting running solar cooling model [3]. Others parameters remain unchanged. Predominantly, two models are compared (see Fig. 2):

a) All pumps placed before solar cooling system components



b) All pumps placed after solar cooling system components

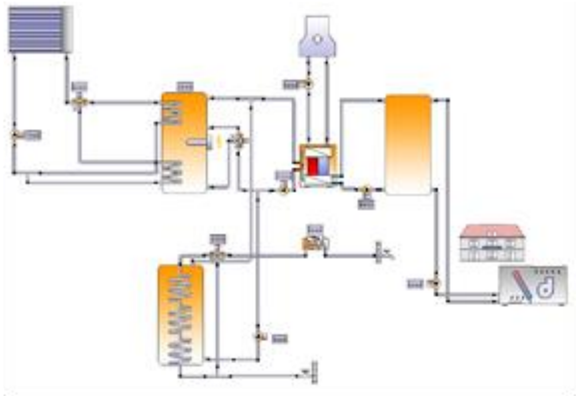


Fig.2. Principle scheme of a) and b) variant.

The yields of the overall solar cooling system and its elements will be evaluated in the results section.

Temperature of the heat carrier increases due to supplied thermal energy. The effectiveness of heat-driving chiller, cooling tower, indoor fan coil and heat exchanger depends on the temperature difference between the heat carrier temperature and the second environment – fluid, outdoor or indoor air. The energy transferred from the pump to the heat carrier is eventually fully converted to heat. It, in its turn, will positively impact the solar thermal cooling elements.

Pump location is not changed in solar collector loop, because the possibility of pump overheating exists. This is extremely important when the pump is located close to the solar collectors and overheated, or even gaseous, antifreeze or glycol could enter the pump and cause thermal damage. As can be seen from Table 1, the maximum temperature in the annual experiment reached 124 °C, and it is possible that this temperature could be even higher in solar collector circuit.

Maximum temperatures of the technical water circuit are close to boiling temperature and are observed in hot circuit and hot water circuit [4].

In the beginning, thermal energy from solar thermal system passes through driving heat circuit. Installing the pump before the thermal driven chiller is a more efficient solution in this circuit. Nominal driving temperature in the circuit is 55–95 °C. Actually, the working average temperature is close to 60–63 °C. The pump operates from 4.7% in NR to 11% of year time in SR. The pump in this circuit consumes from 8kWh/a in NR till 19.5 kWh/a in SR. The given pump transfers from 8.5 till 13% energy from electricity consumption to the heat carrier, or from 1 kWh/a in NR till 2.5 in SR.

TABLE I

TEMPERATURES IN CIRCUITS OF SOLAR COOLING SYSTEM

	North Region			South Region		
	Flow Average Temperature	Return Average Temperature	Max temperature	Flow Average Temperature	Return Average Temperature	Max temperature
	C°					
Pump at chilled water circuit	17.8	17.9	28.9	21.9	22	38
Pump at cold water distribution	21.2	21.9	29	26.4	26.9	38
Pump at driving heat circuit	61.6	58.3	98.6	61.7	58.7	96.9
Pump at re-cooler	26.2	25.4	41.2	26.8	26	42.5
Pump at solar loop	43	61.2	122.1	58.2	76	124.5
Pump at Heat to Hot water	40.5	39	99.7	61.8	60.1	99.8

TABLE II

A) PUMP ENERGY FLOWS

North Region	**A variant**			**B variant**		
	Electricity Consumption	Energy to the system	Heat losses	Electricity Consumption	Energy to the system	Heat losses
	kWh					
Pump at chilled water circuit	8.3	2.5	5.8	8.3	2.5	5.8
Pump at cold water distribution	29.1	8.5	20.6	29.1	8.6	20.6
Pump at driving heat circuit	8.2	0.7	7.5	8.2	0.9	7.3
Pump at re-cooler	20.7	5.9	14.8	20.7	5.9	14.8
Pump at solar loop	39	7.6	31.4	38.9	7.5	31.4
Pump at Heat to Hot water	37.9	7.6	30.4	38.1	7.7	30.5

B) PUMP ENERGY FLOWS

South Region	**A variant**			**B variant**		
	Electricity Consumption	Energy to the system	Heat losses	Electricity Consumption	Energy to the system	Heat losses
	kWh					
Pump at chilled water circuit	19.4	5.5	13.9	19.4	5.5	13.9
Pump at cold water distribution	69.1	19.7	49.3	69.1	19.8	49.3
Pump at driving heat circuit	19.3	2.3	17	19.2	2.5	16.7
Pump at re-cooler	48.6	13.8	34.8	48.5	13.9	34.7
Pump at solar loop	47.6	7.6	40	47.6	7.6	40
Pump at Heat to Hot water	22.5	1.5	21	23.1	1.7	21.5

In chilled water circuit it is also useful to put the pump before the thermal driven chiller, in this case recently cooled coolant is not heated. The nominal operating temperature in circuit is 6-20 °C, while the actual average operating temperature is around 17.8 - 22 °C. From 8.3 kWh/a in NR till 19.4 kWh/a in SR is spent for pump operation. From 28.4 till 30.1% of energy from the spent electricity is transferred to the heat carrier, it corresponds to 2.5 kWh/a in SR and 5.5 kWh/a in NR.

The generated heat of thermal driving chiller plus the heat from indoor are rejected through the re-cooling tower. It is useful to place the pump in heat re-cooling circuit before the re-cooling tower. Nominal operating temperature in the circuit is 22-37 °C, the actual temperature is about 26 - 26.8 °C. The pump consumes from 20.7kWh/a in NR till 48.6 kWh in SR.

The longest operating pump is the one in hot water circuit and the operation time reaches up to 73.4% per annum.

Taking into account that the temperature of the heat carrier loop is given as being high enough, during operation of this pump 37.9kWh/a of electricity is consumed and 20.2% of this energy or 7.6kWh/a is transferred to the system.

Temperature data described above and the rest of the circuit are shown in Tables 2a) and 2 b). We can conclude that positioning the pumps correctly, it is possible to efficiently use additionally from 25 kWh/a in NR up to 43 kWh/a in SR.

Looking at the component yields of the solar cooling system of A and B versions, the effects of pump positioning can be observed. If the pump is placed in an ideal-case scenario (Option A) if compared to the worst-case scenario (Option B), the additional loaded heat transferred to thermal driven chiller is from 5.4 kWh/a in NR till 11.7 kWh/a in SR. In this case, adsorption chiller works by 0.6-1.3 hours more and produces from 3.2 kWh/a in NR up to 4.4 kWh/a in SR more cold, it constitutes 0.15 and 0.11% of the total annual yield. Accordingly, the re-cooling tower rejects 0.8-1.2kWh/a more heat. Additional heat and total required quantity of electricity is reduced by up to 0.24% per year, or 5.1kWh in NR. It should also be mentioned that the more preferable systems use in ideal-case scenario decreased amount of heat from solar collectors about 0.21% of 28kWh/a. in NR. And it not effects on overall positive impact.

III. Conclusions

Solar cooling is topical and profitable in the Baltic Sea region countries. It is important to underline that solar cooling allows not only effectively use solar collectors, but also significantly reduces fossil fuel use for cooling. Solar cooling gives the possibility to provide comfort conditions in the workplace, as ensuring the indoor temperatures corresponding to health standards remains very topical in our country as well as in the neighboring countries.

Annual cool production of solar cooling system is up to 230 kWh per every kWp of adsorption chiller nominal power. 560 kWh of thermal energy are used for this purpose and 89% of this energy is produced by solar collectors. 29% of the total solar thermal energy produced is spent in adsorption cooling process, 60% is used for hot water preparation, the rest is heat losses.

Generally, auxiliary heat request for adsorption chiller requires only 0.6% of the total energy demand in the cooling season, the rest is provided by solar thermal systems heat production. Spending an average of 0.92 parts of heat energy and 0.08 parts of electricity, it is possible to chill 0.38 parts of heat.

Mostly electricity is consumed for fan cooling towers in solar cooling process, and it constitutes 82% of the total electricity consumption for solar cooling process during the year. Pumps are the next major consumer of electricity; they account for 16.6% of the total electricity consumption in the cooling season.

Thermal-driven chiller consumes only 2.9 kWh/y or makes up 0.9% of total electricity consumption.

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