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Solar Cooling in High Latitudes Conditions

Peteris Shipkovs, Andrejs Snegirjovs, Galina Kashkarova, Kristina Lebedeva, Janis Shipkovs and Lana Migla

Institute of Physical Energetics, Riga (Latvia)

Abstract

The renewable energy sources (RESs) occupy a significant part in the energy sectors of Latvia and neighbouring countries; therefore, new solutions for electricity, heat and cold production using different RESs including solar energy are sought for. Since it could be necessary to maintain an optimum indoor microclimate in the summer time – e.g. in hotels, office buildings, manufacturing premises (mainly concrete and glass structures) – small-scale use of solar refrigeration is important.

In the climatic conditions of the Baltic Sea region cooling is required for 3000 - 5000 degree hours per year. So far, in Latvia solar cooling systems have not been used; therefore, it is important to assess the potential of such systems. At the Institute of Physical Energetics a solar cooling system with the cooling capacity of 8 kW is installed in the Solar Energy Testing Park. The system has appropriate measuring equipment; its performance is improved, and the operating data are monitored.

The paper presents new methods for efficient use of solar energy for cooling based on experimental data. The results obtained allow for evaluation of the potential of relevant technologies taking into account their strengths and weaknesses as well as for promotion of innovative technology transfer from science to practice.

Key-words: Solar energy, solar cooling, chiller

1. Introduction

In Latvia and in Europe as a whole it is highly actual to maintain optimum microclimate in diversified facilities, for which every year huge energy resources are spent. The indoor temperature is mostly affected by space heaters and passive solar radiation that enters inside through supporting structures.

Solar energy is available at the same time when it is needed for cooling (Henning, et al., 2013), so solar cooling systems are suitable also for Latvia. In the Latvian climatic conditions the average outdoor air temperature in the summer (May-September) is about 15°C, the maximum daily temperature is from +15°C to +23°C (on average, the maximum temperature in the summer season is + 32.2°C), and the average solar radiation is 1100 kWh/year (the data of the Latvian Environment, Geology and Meteorology Centre (LEGMC)); therefore, the relevant experimental equipment has to operate in the temperature range 55 -95°C in the driving circuit. Possible use, advantages and disadvantages of the system taking into account reduced consumption of fossil fuel for cooling are described below.

Cooling is necessary for 3000 - 5000 degree hours in climate conditions of the Baltic States, while heating – for ~ 90 000 degree hours. The heating season starts at the daily average outdoor air temperatures below +8°C. However, cooling might be demanded already at low outdoor air temperatures and high solar radiation. At the temperatures from +8 to +16°C neither heating nor cooling are usually needed (Shipkovs et al., 2009).

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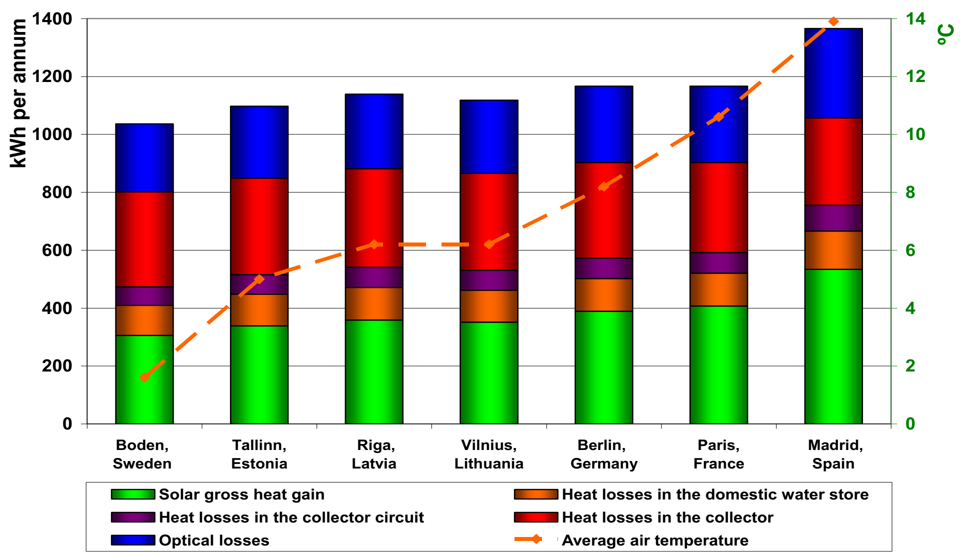

Fig.1: Solar thermal system (STS) productivity and energy losses in different part of STS in different countries

Similar solar thermal systems (STS) of the type were tested in different European regions using a dynamic simulating program. The results were equated to 1 square meter of solar collector absorber. As shown in fig.1, the solar collector's heat losses are larger in the Baltic region than in other European countries (e.g. in Berlin, Paris, and Madrid these are lower by 3 %, 9 % and 13 %, respectively) despite the fact that STS operational time is greater in warmer regions. Considering the proportion of global solar radiation that is absorbed by solar collectors, the heat losses are lower in the collector circuits in warmer regions (Thorpe, 2011). Therefore, the regularities in the heat losses and in the thermal conductivity of STS individual components in the Baltic countries' region differ from those in warmer regions.

The heat production of small capacity solar cooling systems with solar collectors was estimated using PolySun modeling and dynamic simulation program (Shipkovs et al., 2010). The average efficiency of the STS for well-designed thermal systems with glazed flat-plate collectors is about 30-35% in the Baltic countries' region. The efficiency increases up to 35-40% at the use of vacuum tube collectors, which have lower heat losses.

A significant proportion of the heat energy absorbed by solar collectors is lost in the solar collector circuit and the accumulation tank (Lechner, 2014). The losses in solar collector circuit and accumulation tank exceed 30% of the collector field yield in a typical solar thermal system in the Baltic countries' region.

The annual global solar radiation is lower in the Baltic countries as compared with other European countries where solar collectors are more widespread, and the outdoor air temperatures are below the average values in Europe. This creates the need in optimization of solar thermal systems for solar cooling in the Baltic countries' region.

2. Methods and Results

Thermal cooling device starts operation at specified temperature of heat carrier in the inlet from heat production side. The efficiency of thermal-driven coolers increases with the inlet temperature increasing (SCH International Agency, 2011), (SCH International Agency, 2012). The temperature range in heated circuit of thermal-driven cooling devices varies depending on the cooling technology.

In the work, the market of low power solar chillers was investigated. It was observed, that 90% of chillers work on the absorption principle. The temperature range in driving circuit of absorption chiller is 75-110°C using ammonia-water technology and 75-105 °C using absorption water-LiBr technology. The temperature range in driving circuit is lower with adsorption technology. The water-silica gel adsorption technology provides even narrower temperature range of 55-95°C.

The estimated research facility has a cooling capacity of 8 kW. It is envisaged that such systems will be required for the efficient operation with the heat output in the temperature range 55-95 ° C, allowing cooling equipment to operate in single-stage cycle, and cool the coolant circuit of 8-20°C. Consequently, there are many factors that affect the system performance and efficiency of the processes that need to be clarified. It is planned to increase the capacity of the collector at the operating temperature of 55 °C, which, in turn, will enhance cooling in the working hours. The produced cool energy will be used for creation of comfortable microclimate in a research laboratory (Fig.2).

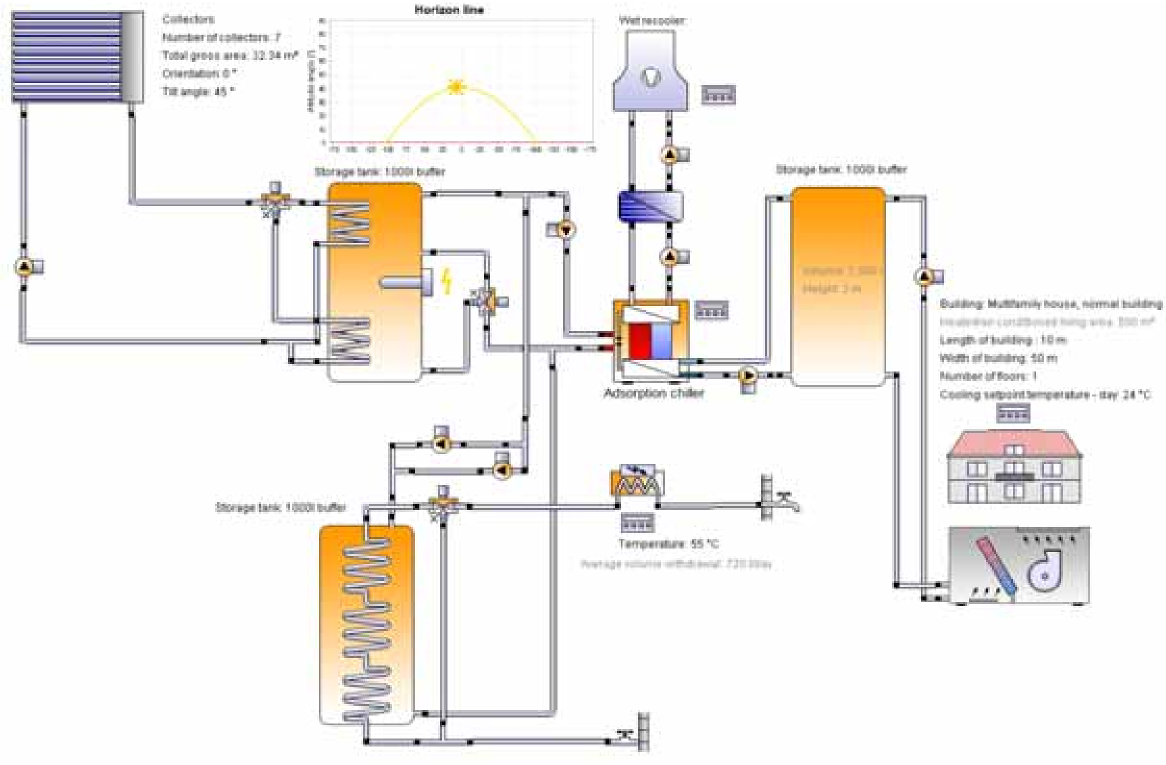

Fig. 2: Principle scheme of solar cooling and hot water preparation

The results of solar cooling investigations will be used for evaluating the potential of the mentioned technologies, with proper account taken for its strengths and weaknesses; besides, these results are expected to serve for promoting innovative technology transfer from science to the practice.

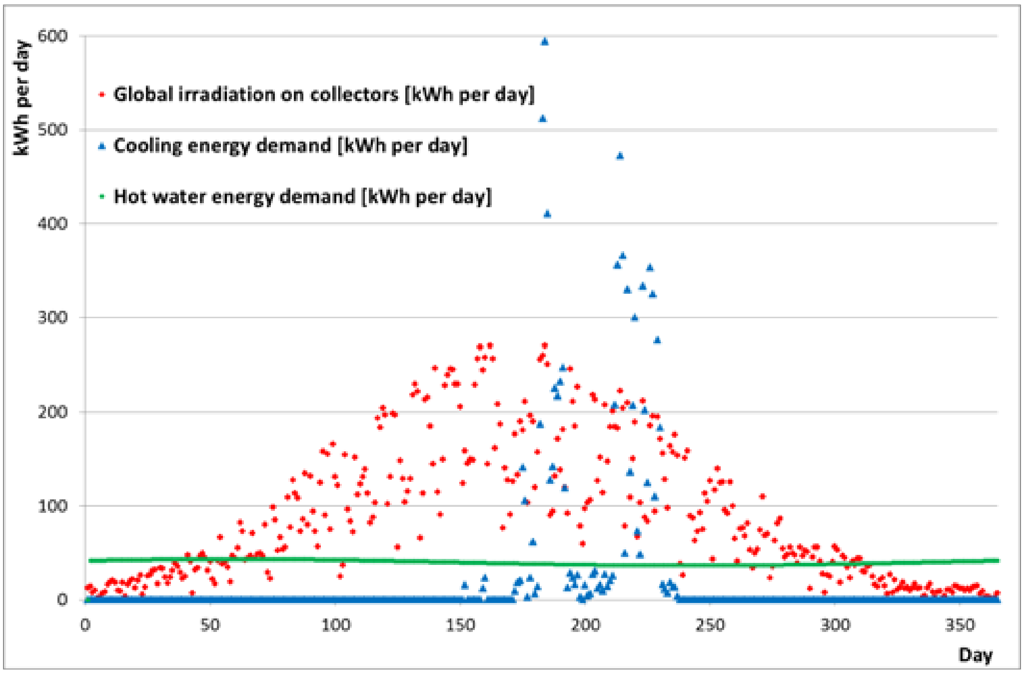

Fig. 3: Solar radiation supply and thermal energy demands

The experiments were performed using a solar thermal system designed for an insulated multi-family house with uneven hot water consumption. The power and capacity of the system was optimized based primarily on the heat demand of thermal driven chiller and on the probable stagnation mode of such systems. The cooling part is designed to cover ~ 80% of peak demand for cooling. On the one hand, this means that in the warmest five days the indoor temperature decreased/s only by 3-5 degrees below the outdoor temperature, and it is probable that the designed temperature will not reach the designed value in these days. On the other hand, this would help to avoid designing an over-power system whose full power will be used but seldom, while adverse thermal and hydraulic losses will persist.

The cold yield of the adsorption-type heat driven chiller reaches 60% of the heat consumption. Fig. 3 shows that cooling demand far exceeds the solar radiation and hence the solar thermal part heat yields in a few days. Three accumulation tanks are used for overcome given peaks: one tank for heat, second for hot waters, third for cold accumulation.

Sometimes hot water and heat accumulation tanks are combining. In this case, on the one hand overall heat losses are reducing because of reduce ratio of surface area to tank volume and thereby reduce thermal conductivity coefficient of accumulation tank. On the other hand, the total volume of the tank increases, which means a longer time for heat accumulation until the inside temperature reaches the nominal for the thermal-driven cooling cycle; the cooled heat carrier prepared for thermal driven cooling cycle (t_{nom} =65-95°C) will be running in a hot water circuit (t_{max} =50-55°C); also, it could be difficult to place such a large accumulation tank indoors and distribute from it.

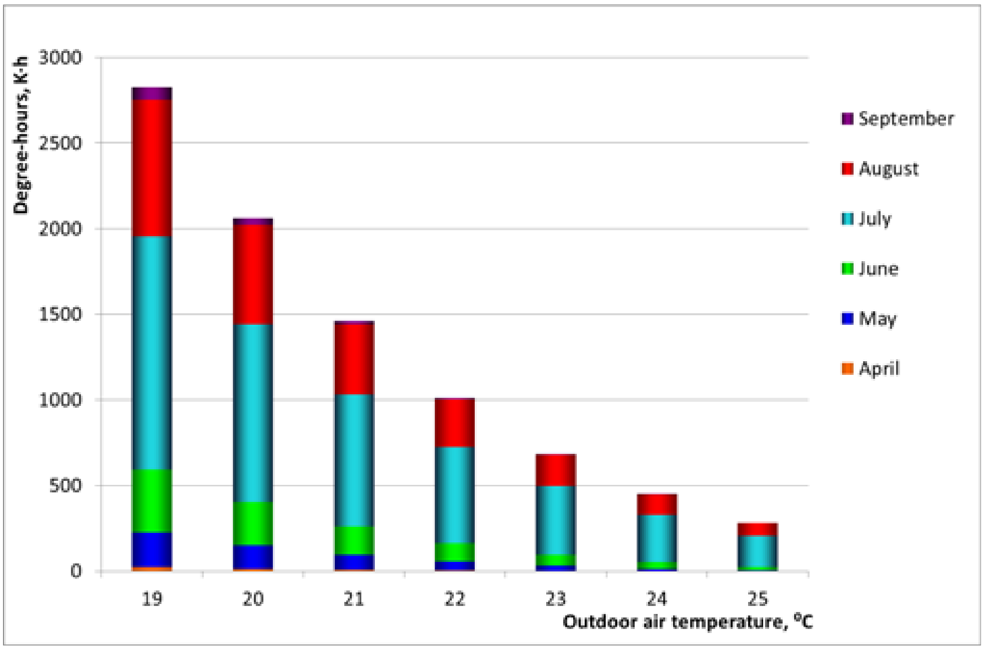

Fig. 4: Degree hours vs. defined outdoor air temperature in the Baltic States region

As seen from fig. 4 diagram, the outdoor air temperature exceeds 22°C only for 1000 degree hours. This makes possible appropriate use of the heat rejection towers of thermal cooling system (which effectively operate under given conditions) by reducing the heat carrier temperature in the heat rejecting circuit from 32 to 27°C.

The tilt angle for the maximum heat production was defined by changing such an angle of solar collector by model simulation. At the annual maximum solar collector production the tilt angle (~45 degree) does not coincide with that at the maximum solar collector production in a cooling period (~30 degree). This is because the Sun is closer to zenith in summer. The larger tilt angle is profitably used only if additional heat consumption is sufficient. In this case the additional annual gain is only 30kWh from each square meter of solar collector.

Therefore, we have developed a combined system for solar cooling and hot water preparation as well as identified the optimization proposals. The developed system relies upon the first priority of using the heat from solar collectors for cold productions, with a thermal driven chiller operating in a cooling season.

Using thus designed solar cooling system it is possible to cover up to 80% of the maximum cooling capacity. The inferences that could be drawn from the results obtained at using the system are as follows:

-This system can be used for both cooling and hot water production. Therefore it is necessary to choose solar collectors with lower heat loss coefficient (a1<1.5W/m^2/K). This mostly increase solar collector yield in non-cooling season. Choosing the solar collectors with higher optical efficiency (η>0.74) will also raise the total solar thermal yield.

- Based on the previous studies and taking into account the Latvian climatic conditions (the LEGMC data) it has been determined that the low- and medium-power solar cooling systems should have the ratio of the solar collector power at ΔT=70K to the adsorption chiller power from 1.65 to 1.85.

- The annual cold production of solar cooling system is up to 230 kWh per kWp of adsorption chiller nominal power. For this are used 560 kWh of thermal energy and 89% of it produced with solar collector. In this process re-cooler uses 38.5 kWh electricity for reject heat, that was spent in the thermally driven cooling process and waste heat from indoors.

The heat that has not been spent in adsorption process is used for hot water preparation.

29% of the total solar thermal produced energy is spent in adsorption cooling process, 60% - is used for hot water preparation, the rest of the heat is released in the form of heat loss.

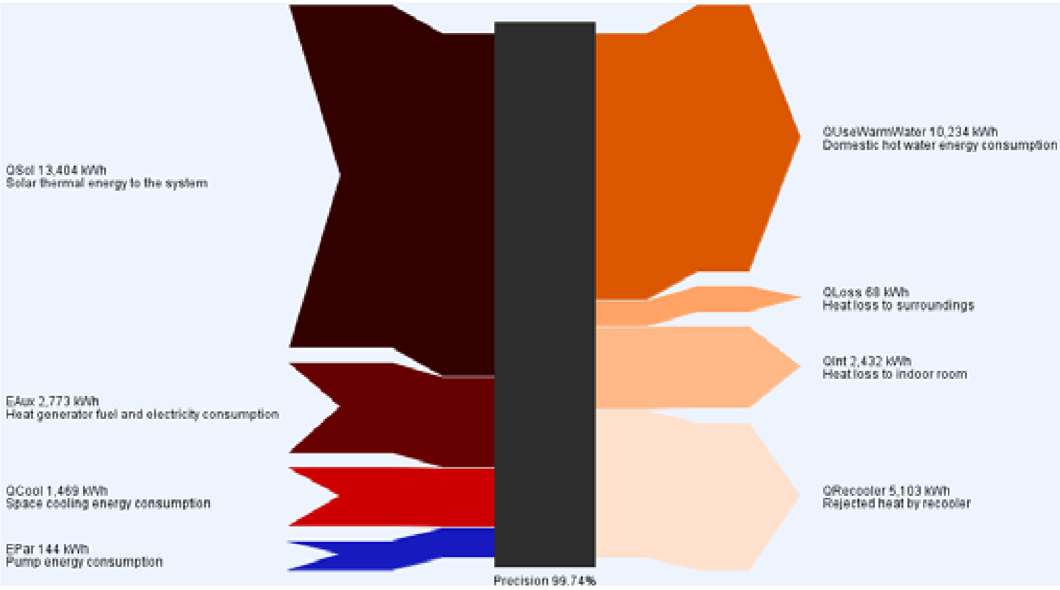

Fig. 5: Annual energy flow diagram

The annual energy flow balance shows that most the heat energy is produced by the solar collectors (Fig.5) Additional thermal energy is required for thermally-driven cooling and for hot water preparation. In this case 14% of auxiliary energy is consumed by the hot accumulation tank for reaching the nominal temperature of adsorption cycle in cooling season. The indoor heat losses make quite a quite large proportion of the energy balance. On the one hand, the indoor heat losses are favorable in heating season, while on the other these are undesirable in cooling season. Therefore it is appropriate to design regulated forced ventilation in the engine rooms.

In a cooling season the heat is used primarily for operation of thermal driven chiller through which cooled water in cold accumulation tank. In this time period the unnecessary heat is spent for hot water heating, which increases the solar collector yield thus raising the overall system efficiency. Besides, the redirection of excessive heat to the hot water production reduces the total time of solar collector's idle operation. In turn, this would prolong the life of solar collectors.

Excessive thermal energy can be utilized for hot water preparation in the cooling season provided that the following conditions are met:

- the building does not require cooling;

- the water temperature at the top of the cold accumulation tank reaches the minimum of cooled temperature of the cooling machine (~9-11oC);

-the water temperature at the top of hot accumulation tank reaches the critical maximum (~90-95oC).

Up to 78% of heat required for hot water preparation can be provided by heat generated by solar collectors in non-cooling season.

3. Conclusions

Conclusions based on the results of work are as follows.

Solar cooling is actual and profitable in Baltic See regions, allowing effective use of solar collectors and significant decrease in consumption of fossil fuel for cooling. Solar cooling makes it possible to maintain comfort conditions at the workplaces in compliance with the health standards adopted in our country as well as in neighbouring countries.

The annual cold production of solar cooling system is up to 230 kWh per kWp of nominal power of the adsorption chiller. For this purpose 560 kWh of thermal energy are required, with 89% produced by solar collector. Of the total solar thermal energy produced 29% is spent in the adsorption cooling process and 60% – for hot water preparation. The rest are heat losses.

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