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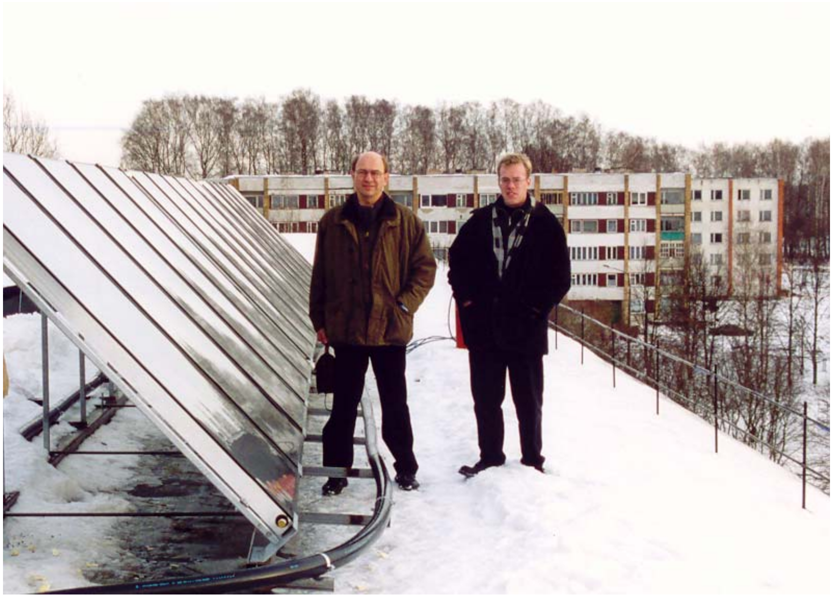

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1 Introduction

In 2001 it was decided to built two solar heating systems at Aizkraukle secondary school no. 2 in order to gain experience with solar heating systems under Latvian conditions. The project is financed by the Danish Energy Authority.

Latvia is one of the Baltic countries at the coast of the Baltic Sea between the latitude 55° and 58°N. Aizkraukle is situated about 90 km from Riga, the capital of Latvia. The solar radiation in Riga, (latitude 57°N), is somewhat lower than the solar radiation in Copenhagen, Denmark (latitude 56°N), see Fig. 1. The average outdoor temperature is somewhat lower in Riga than in Copenhagen, see Fig. 2.

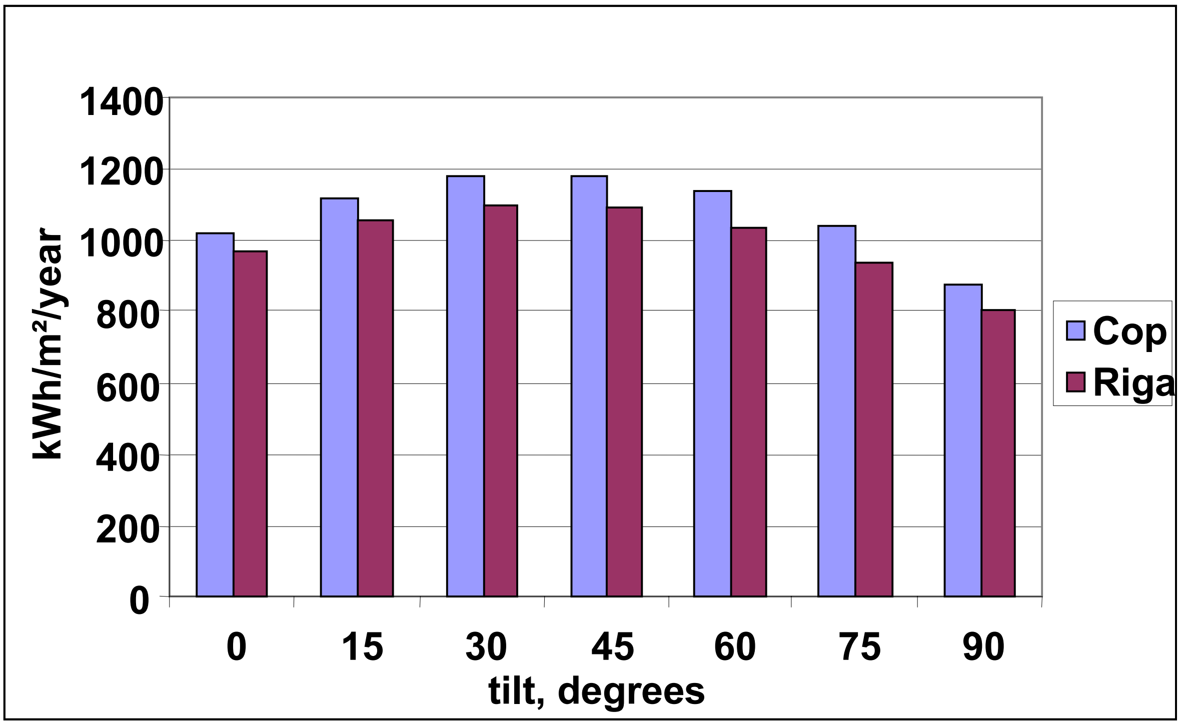

Fig. 1. Yearly solar radiation on a south facing surface in Riga and Copenhagen.

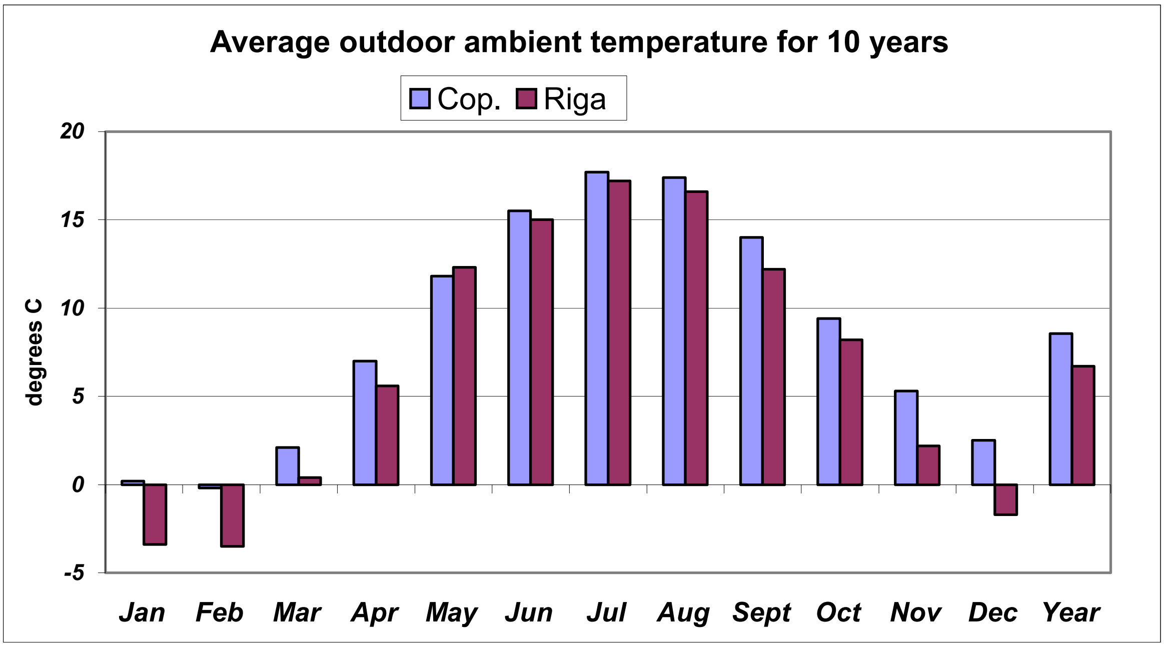

Fig. 2. Average outdoor ambient temperature in Riga and Copenhagen.

Weather data from a Test Reference Year for Latvia worked out by Mofid et al. [1] were used as inputs for simulation models used by Mofid et al. [2] to calculate the thermal performance of differently designed solar heating systems for Aizkraukle secondary school no. 2. The designs of the two solar heating systems were determined by means of these calculations, by means of cost estimates and by means of experience from the operation of similar solar heating systems installed in Denmark.

One of the solar heating systems is a solar domestic hot water system, a SDHW system for the school including the sport facilities. The other system is a solar heating plant connected to the district heating network.

Investigations by Furbo et al. [3] have shown that large SDHW systems designed as low flow systems with a highly thermally stratified hot water tank with an external heat exchanger and stratification inlet pipes perform much better than traditional SDHW systems. Further, investigations by Carlsson [4] have shown that the thermal stratification in solar hot water tanks and by that the thermal performance of SDHW systems are highly influenced by the design of the inlets to the tank.

The SDHW system in Aizkraukle is therefore designed as a low flow system with a hot water tank equipped with stratification inlet pipes, inlets designed according to the design rules developed by Carlsson et al. [5] and with an external heat exchanger.

The solar heating plant in Aizkraukle is designed as a traditional solar heating plant.

2 System designs

The SDHW system is a low flow system based on 15 BA22 solar collector panels from Batec A/S with a total collector area of 32.9 m² and on a 2000 l hot water tank in which thermal stratification is built up during operation of the solar collectors.

A schematic illustration of the solar heating system and of the hot water tank is shown in Fig. 3 and Fig. 4 respectively.

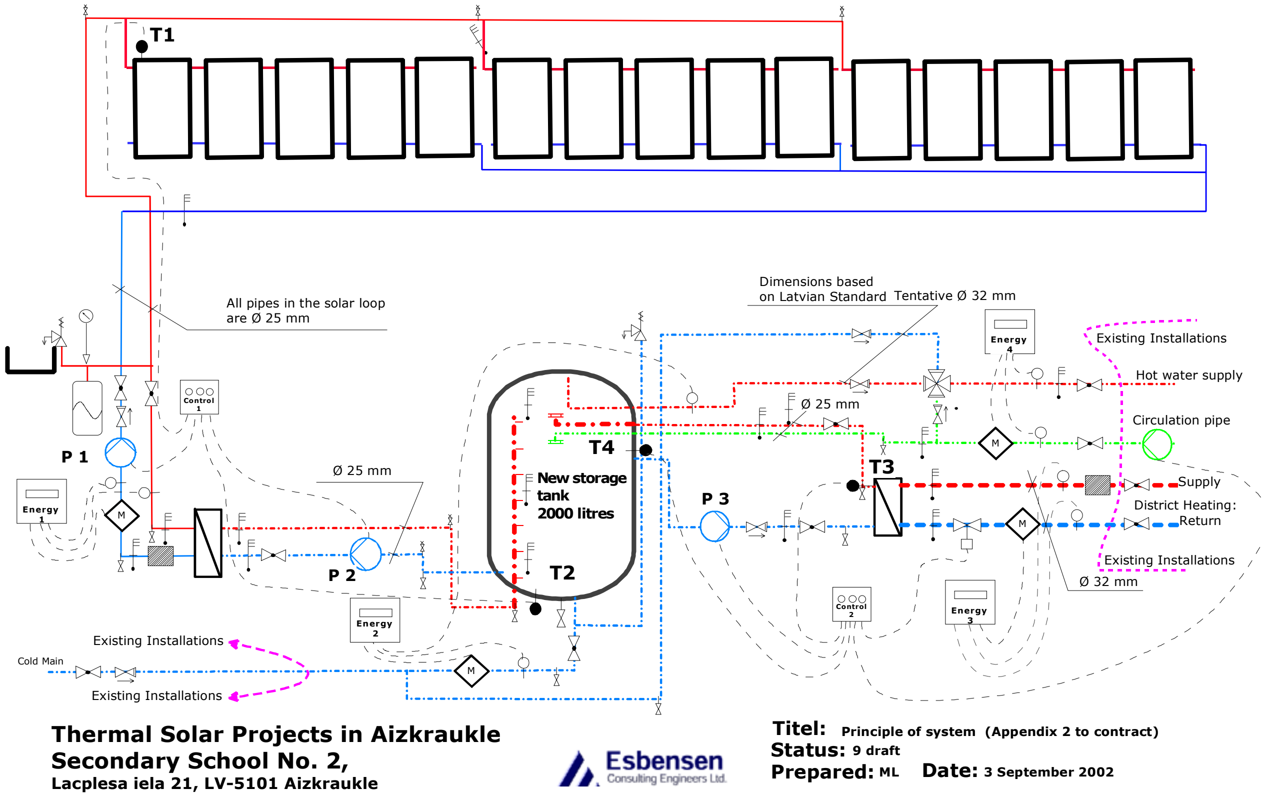

Fig. 3. Schematic illustration of the SDHW system for the school.

A 45% (weight%) propylene glycol/water mixture is used as the solar collector fluid. The 15 collector panels are installed in 3 parallel connected collector fields each consisting of 5 panels. The volume flow rate in the solar collector loop is about 0.2 l/min per m² collector and an external heat exchanger is used to transfer the heat from the solar collector fluid to the domestic water. The domestic water, which is placed in the 2000 l hot water tank, is pumped with a volume flow rate of about 6 l/min from the bottom of the tank to the heat exchanger and back to the hot water tank through stratification inlet pipes marketed by SOLVIS-Solarsysteme GmbH.

A SOLVIS stratification inlet pipe is equipped with one flap which is either closed or open depending first of all on the temperature level inside and outside the flap. Fig. 5 shows schematic illustrations of a SOLVIS stratification inlet pipe and Fig. 6 shows photos of a SOLVIS stratification inlet pipe and of 5 compound inlet pipes.

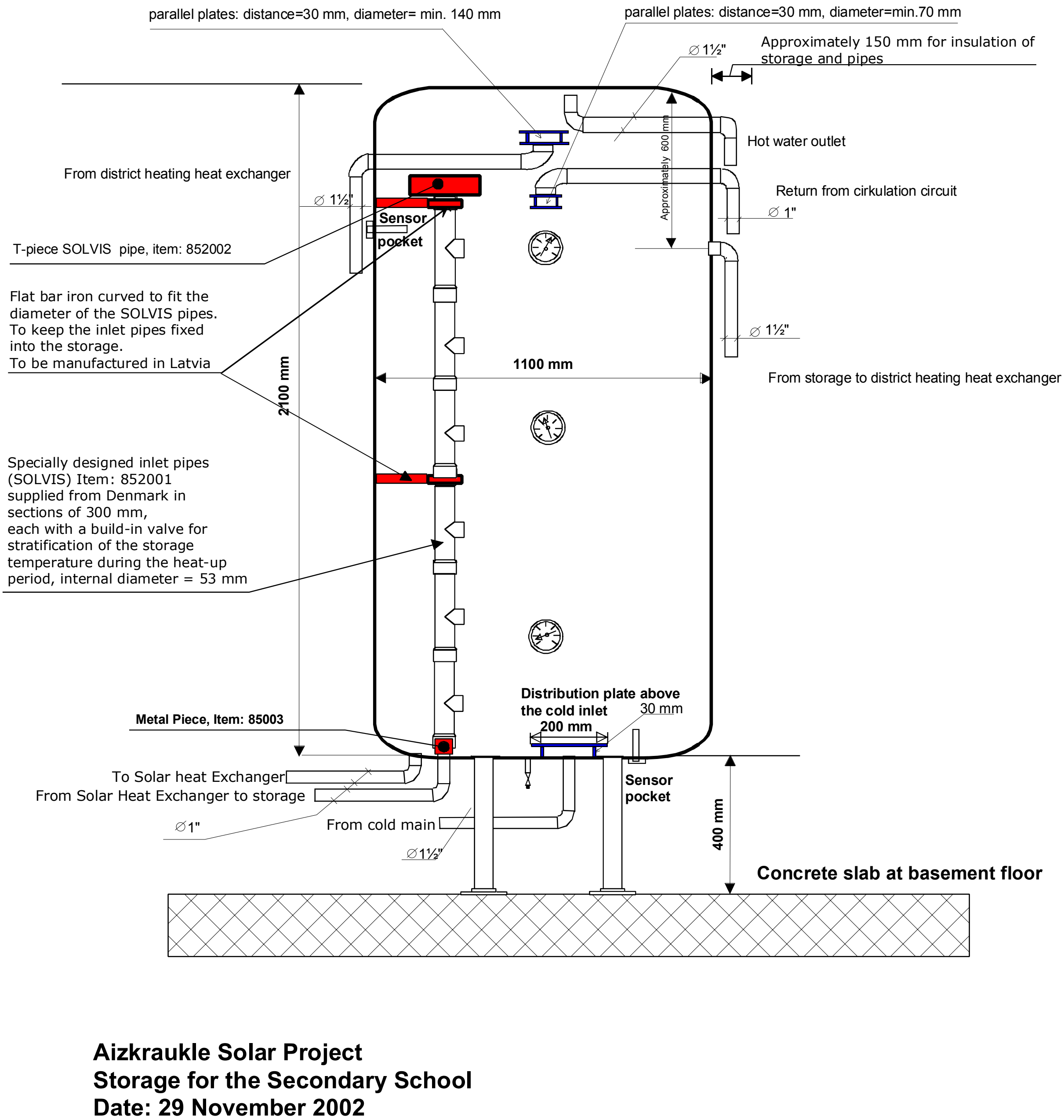

Fig. 4. Schematic illustration of the hot water tank of the SDHW system for the school.

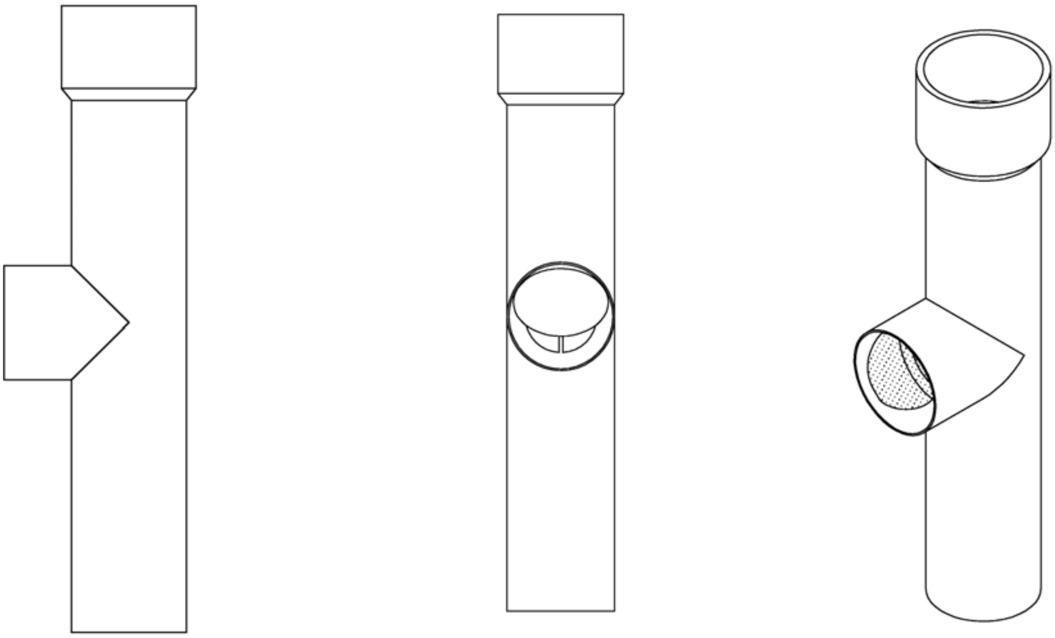

Fig. 5. Schematic illustration of a SOLVIS stratification inlet pipe.

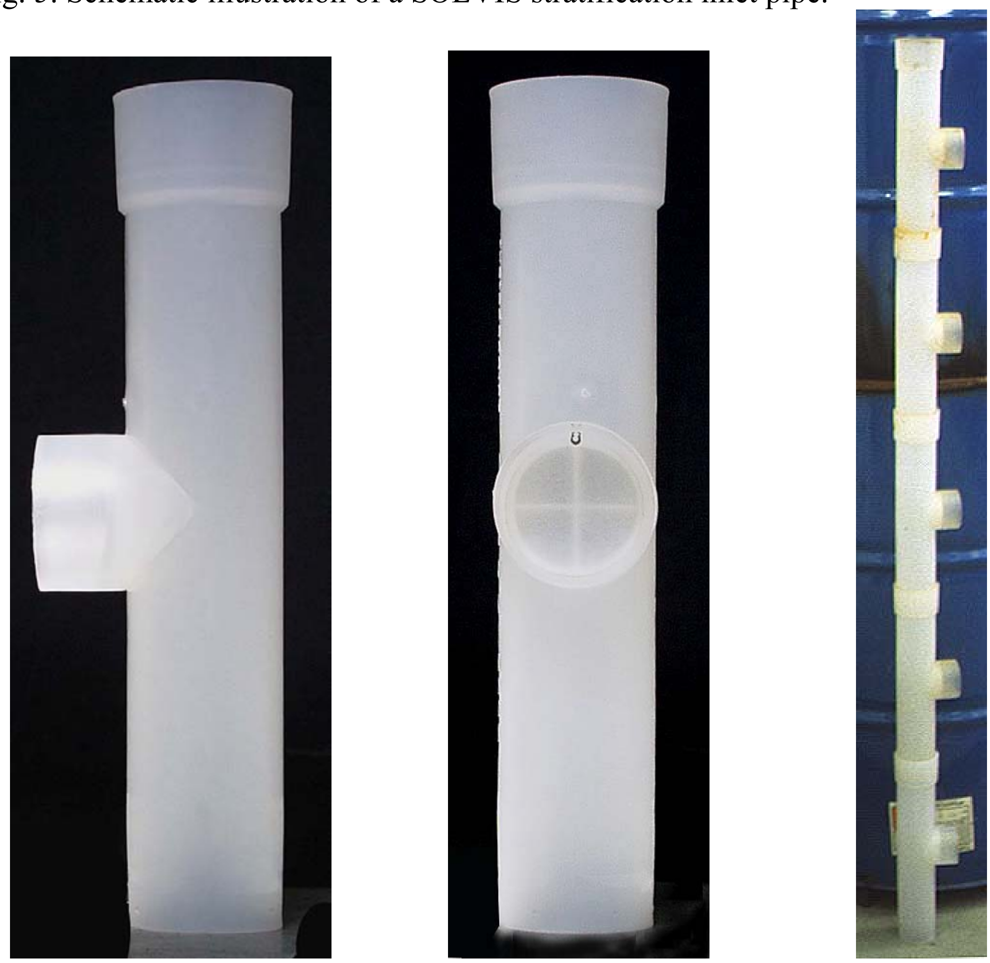

Fig. 6. Photos of a SOLVIS stratification inlet pipe and (right) 5 compound inlet pipes.

Shah [6] found that thermal stratification in a tank is built up in a good way by charging through the SOLVIS stratification inlet pipes as long as the volume flow rate is between 5 l/min and 10 l/min. A volume flow rate in the heat exchanger loop of about 6 l/min is therefore suitable.

The domestic water in the hot water tank can be heated by the solar collector fluid and by means of district heating in periods when the total hot water demand cannot be covered by the solar collectors.

If the temperature in the top of the hot water tank is lower than 55 °C domestic water is circulated from the upper part of the tank through an external heat exchanger where the district heating can heat up the water. The domestic water enters the top of the tank through an inlet designed as two parallel plates in order to avoid mixing by the entering water as reported by Carlsson et al. [5]. The upper 500 l of the tank is heated by the district heating.

The hot water system is equipped with a circulation pipe with a flow rate of about 12 l/min. The water returning from the circulation pipe enters the top of the tank through another inlet designed as two parallel plates, also to avoid mixing by the entering water.

The cold water enters the bottom of the tank through another inlet design based on a plate in order to avoid mixing during draw-offs and the hot water is tapped from the top of the tank.

On Fig. 4 it is also noted that all pipe connections just outside the side of the tank are lead downwards. This is done in order to reduce the heat loss from the connections to a minimum. The design of the hot water tank ensures that thermal stratification is well built up during all hours of operation. It is therefore expected that the SDHW system will have a high thermal performance.

The solar heating plants consists of 10 BA 120 T solar collector panels from Batec A/S with a total collector area of 120 m². Fig. 7 shows a schematic illustration of the solar heating plant.

The system consists of 5 parallel connected rows of solar collector panels. Each row has two serial connected panels. The solar collector fluid is also in this system a 45% (weight%) propylene glycol/water mixture, which transfers the solar heat from the solar collectors to the district heating network by means of a heat exchanger.

Fig. 8 and Fig. 9 shows photos of the solar collectors of the SDHW system and solar heating plant, respectively.

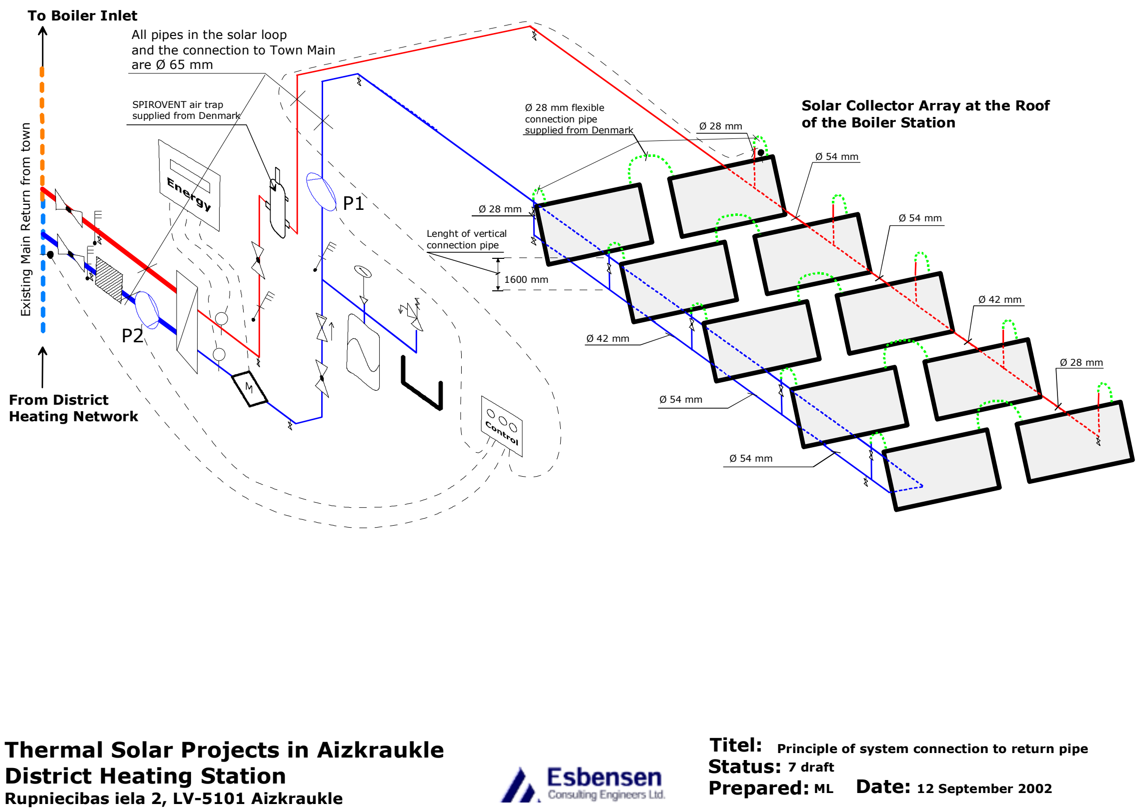

Fig. 7. Schematic illustration of the solar heating plant.

Fig. 8. Photo of the collectors of the SDHW system.

Fig. 9. Photo of the solar heating plant.

3 Theoretical calculated thermal performance of the systems

Prior to the installation of the SDHW system it was estimated that the daily hot water consumption of the school including the sport facilities is situated in the interval from 2000 l to 3000 l corresponding to a yearly energy consumption in the interval from 33400 kWh to 50100 kWh. A yearly heat loss from the circulation pipe of 14900 kWh is assumed and a flow rate through the circulation pipe of 11.7 l/min during the whole year is assumed.

The yearly net utilized solar energy of the SDHW system was calculated for different heat storage volumes, solar collectors, solar collector areas and hot water consumption with the program TRNSYS [7].

Latvian weather data were used as input to the program. The efficiencies of the solar collectors used in the calculations are shown in Fig. 10 for a solar irradiance of 800 W/m² and an incidence angle of 0°.

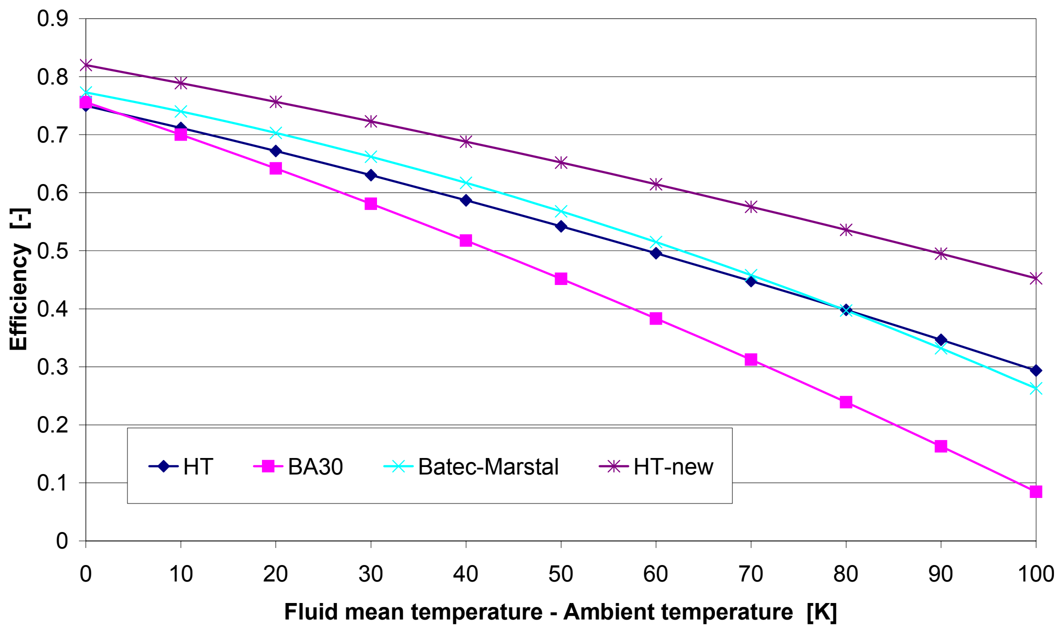

Fig. 10. Efficiency of solar collectors as a function between the mean solar collector fluid temperature and the ambient air temperature.

Fig. 11 shows calculated net utilized solar energy as functions of the heat storage volume and the hot water consumption. The solar collector assumed in the calculations is HT-new with a total collector area of 37.5 m².

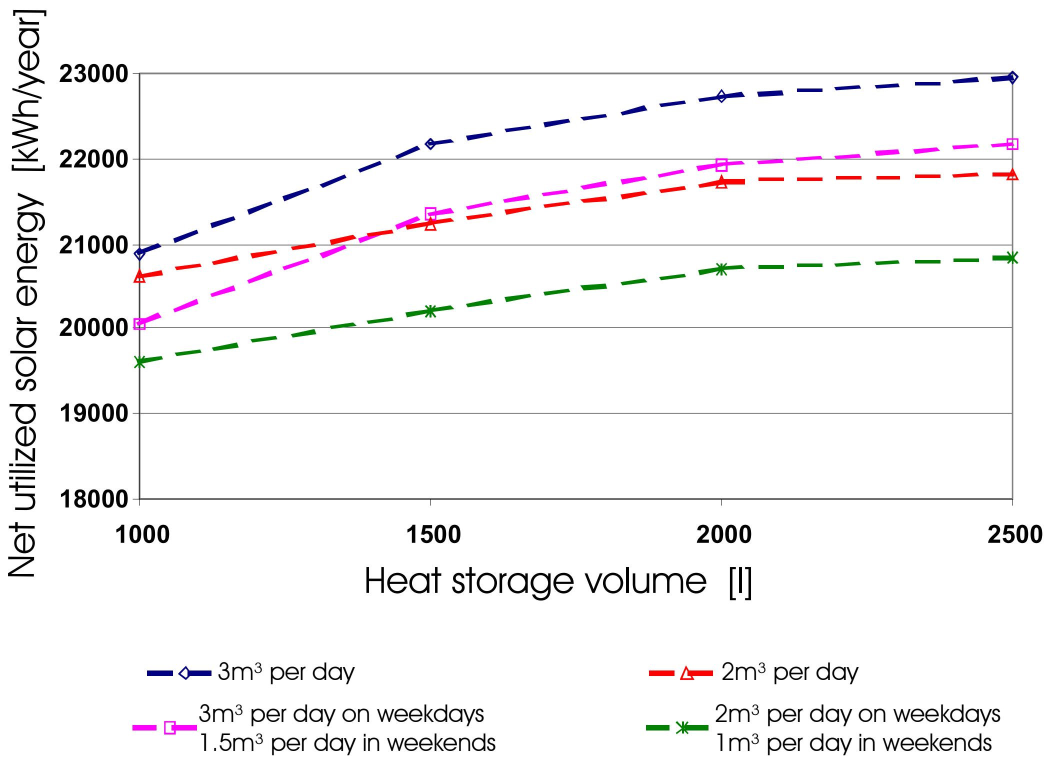

Fig. 11. Net utilized solar energy for the SDHW system as function of the heat storage volume and the hot water consumption.

Fig. 12 shows calculated net utilized solar energy as function of the heat storage volume and the solar collector. The hot water consumption is 3000 l per day and the collector area is approximately 40 m².

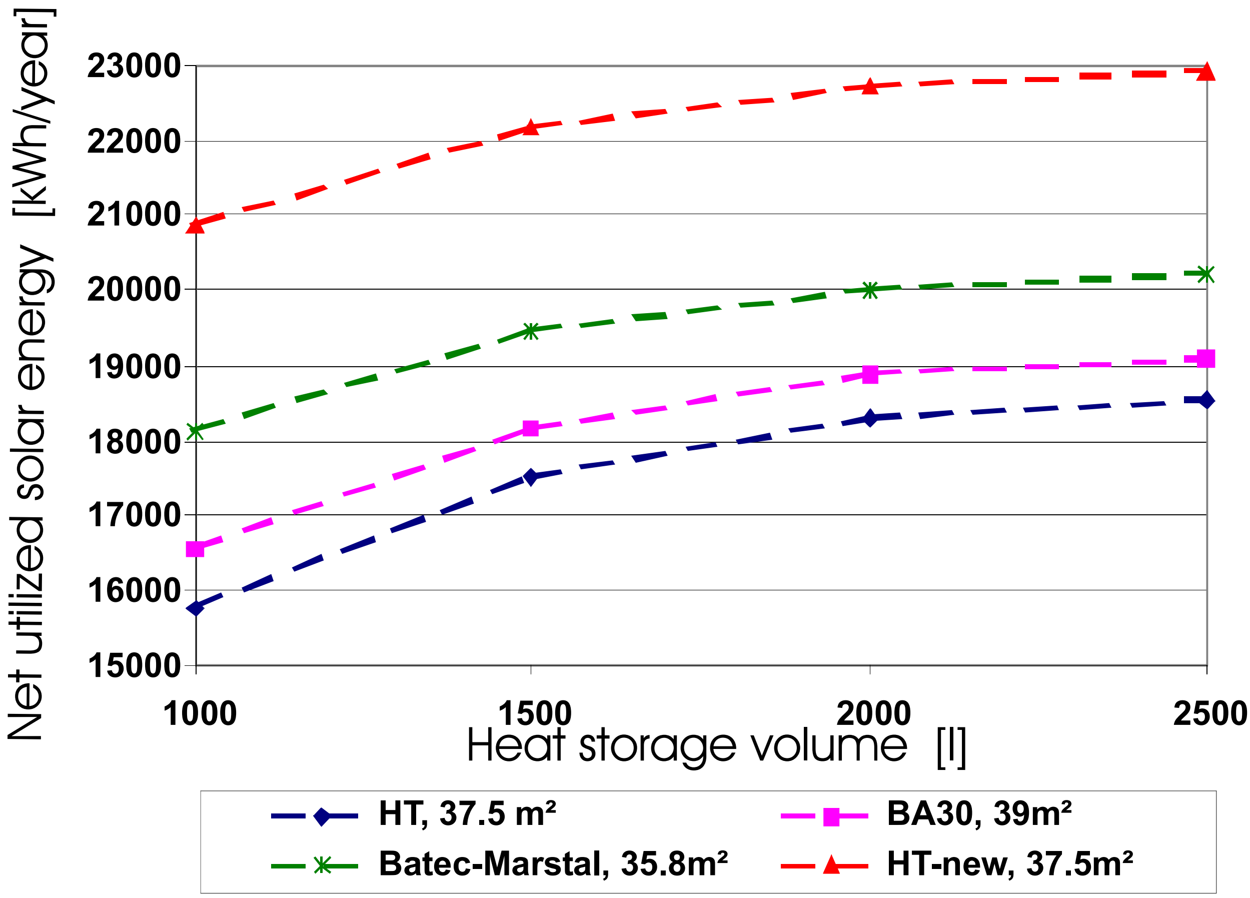

Fig. 12. Net utilized solar energy as function of heat storage volume and solar collector.

The yearly thermal performance of collectors working at different constant temperatures was calculated with the simulation program *Solvarmecentral*, which was developed by Jensen et al. [8].

Fig. 13 shows for a collector tilt of 40° the yearly thermal performance of a solar heating plant as function of the constant mean solar collector fluid temperature.

The design of the systems was determined by means of the calculated thermal performance and by means of cost estimates.

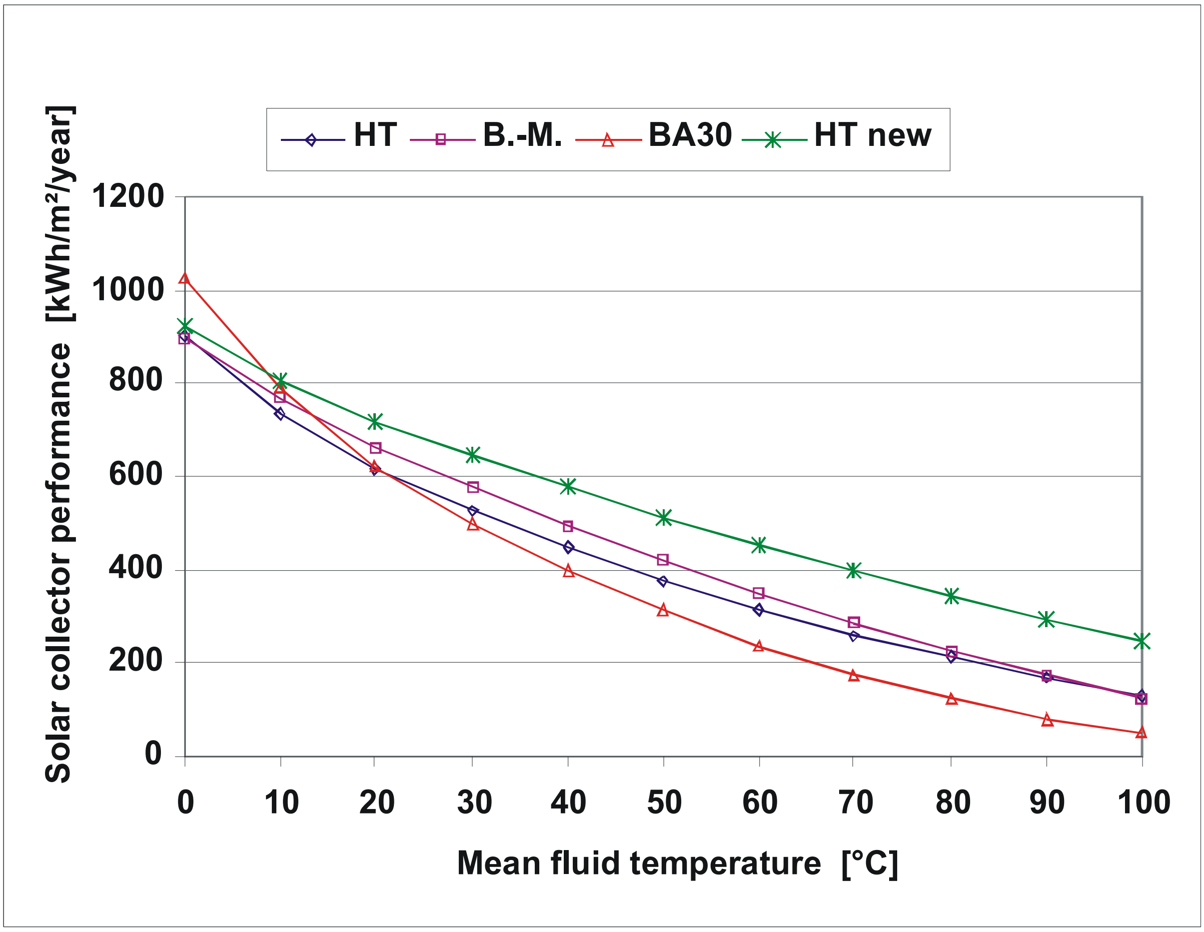

Fig. 13. Yearly thermal performance of a solar heating plant for different collectors and mean solar collector fluid temperatures.

4 Monitoring systems and measured results

The most important energy quantities are measured for both solar heating systems with combined flow and energy meters. The placements of the energy meters are seen in figure 3 and 7.

For the SDHW system the hot water consumption, the heat loss of the circulation pipe, the solar energy transferred from the solar collector fluid to the external heat exchanger and the energy supply from the district heating network to the heat exchanger are measured.

By means of the measurements the net utilized solar energy and the solar fraction of the SDHW system can be determined. The net utilized solar energy is defined as the hot water consumption plus the heat loss of the circulation pipe minus the heat transferred from the district heating network. The solar fraction is defined as the ratio between the net utilized solar energy and the heat demand, which is the sum of the hot water consumption and the heat loss from the circulation pipe.

For the solar heating plant the solar energy transferred from the solar collector fluid to the heat exchanger is measured.

The solar radiation on the solar collectors is also measured.

The measurements started in March 2003. The measuring period ended July 14, 2003. Table 1 and figure 14 and 15 shows measured results for the SDHW system.

Period, 2003	March	April	May	June	July 1-14	Total
Hot water consumption, kWh	671	621	392	83	82	1849
Hot water consumption, l/day	440	453	400	100	156	329
Heat loss from circulation pipe, kWh	3623	3013	2057	2201	696	11590
Solar heat transferred to heat exchanger, kWh	983	1212	899	651	352	4097
Heat from district heating network to heat exchanger, kWh	3759	2815	1844	1877	596	10891
Net utilized solar energy, kWh	535	819	605	407	182	2548
Net utilized solar energy, kWh/m²	16	25	18	12	6	77
Solar fraction, %	12	23	25	18	23	19

Table 1. Measured monthly energy quantities for the SDHW system.

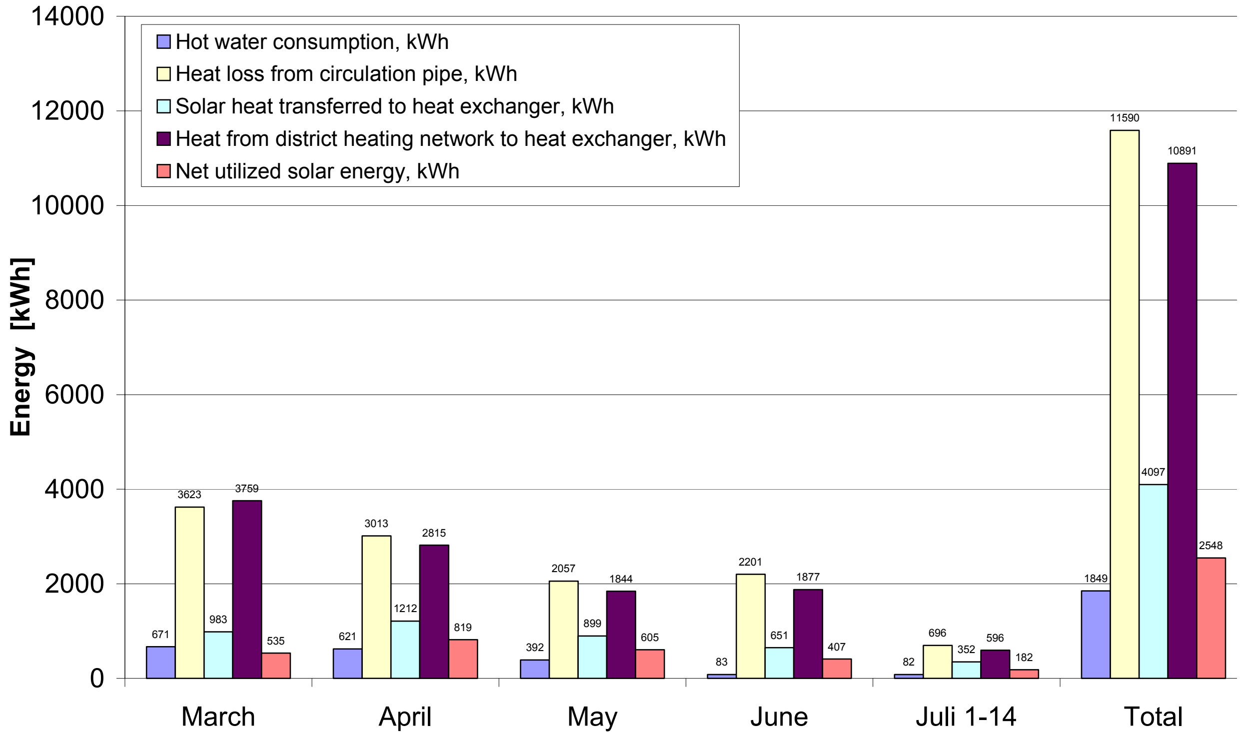

Figure 14. Measured monthly energy quantities for the SDHW system.

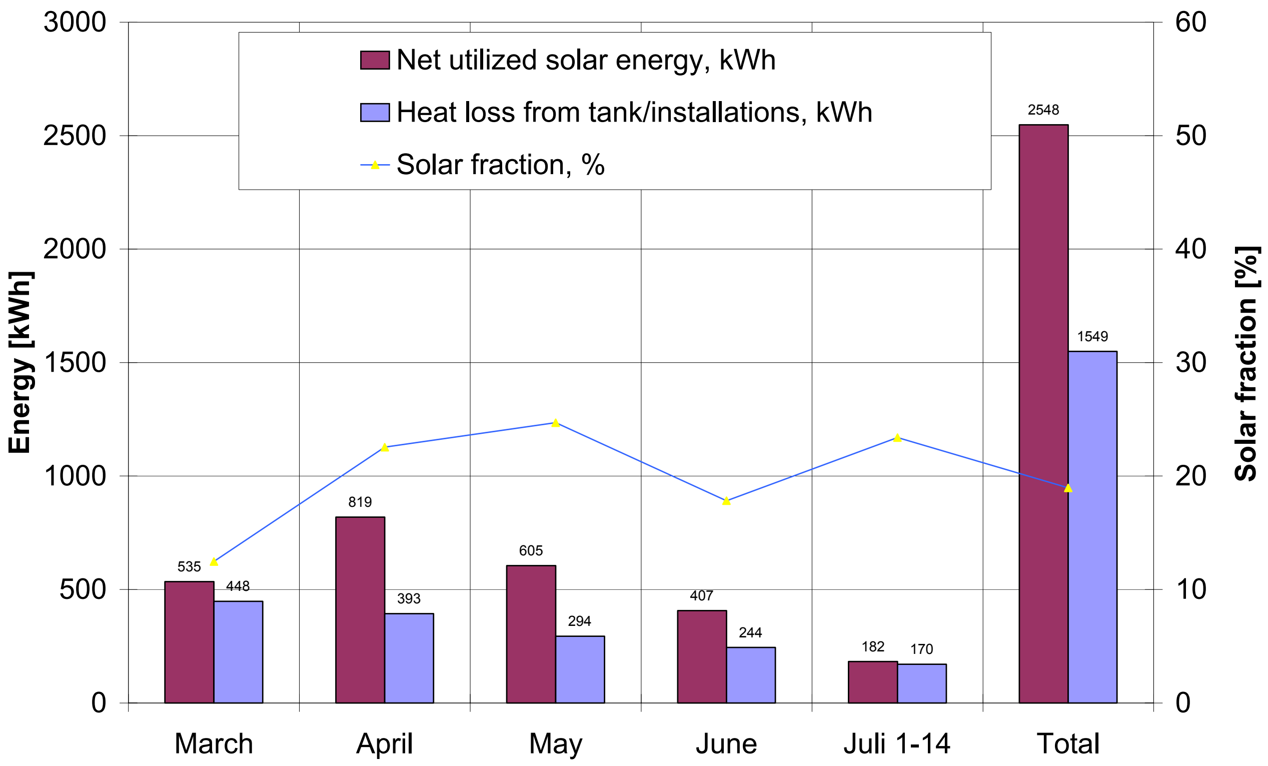

Figure 15. Monthly net utilized solar energy and heat loss from the tank.

The hot water consumption is much lower than expected, especially during the summer. The average daily hot water consumption is about 10 l per m² solar collector. The system is therefore oversized with a factor of 5, and the net utilized solar energy will therefore be much lower than expected. The heat loss from the circulation pipe is much higher than expected. The volume flow rate in the circulation pipe is about 26.5 l/min, which is much higher than expected. This high flow rate results in mixing in the heat storage and in a reduced thermal performance of the SDHW system.

By means of the measurements it is possible to determine the heat loss coefficient of the heat storage of the SDHW system. The heat loss coefficient of the heat storage inclusive the heat exchangers for the solar collector loop and the district heating network is estimated to be about 16 W/K. This heat loss coefficient, which is much higher than expected, will strongly decrease the net utilized solar energy of the system.

From figure 15 it is obvious that the heat loss of the heat storage inclusive heat exchangers and pipe systems connecting the heat storage and the heat exchangers is lower during summer periods than during winter periods. This is caused by the fact that the temperature level in the district heating network and by that the temperature level at the top of the heat storage heated by the district heating network is lower during the summer than during the winter period.

Further, it was observed that the solar collector fluid is boiling in the solar collectors during sunny summer periods. The reasons are that there is air in the solar collector loop and that it is not possible to discharge the heat storage if the heat storage temperature is too high.

Based on the measurements it is estimated that with the present low hot water consumption the yearly net utilized solar energy is 5000 kWh, corresponding to about 150 kWh/m² per year.

Based on the measurements and experience from the operation it is strongly recommended to:

- Stop the flow in the circulation pipe in all periods without hot water demand.
- Decrease the flow rate in the circulation pipe.
- Careful insulate the tank, the pipe connections and the heat exchangers.
- Secure that air is not trapped in the solar collectors.
- Adjust the control system so that heat can be transferred from the tank to the district heating network in periods with too high tank temperatures.

The measured results for the solar heating plant are given in Table 2. The measuring period is March 1, 2003 - October 5, 2003. However, due to start up problems caused by too low flow rates, measurements are only available in the periods: March 1, 2003 - April 22, 2003 and July 17, 2003 - October 5, 2003.

Period, 2003	Thermal performance of solar collectors, kWh	Thermal performance of solar collectors, kWh/m²
March	2026	17
April 1-22	1602	13
May	-	-
June	-	-
July 17-31	4836	40
August	4301	36
September	3896	32
October 1-5	228	2
Total	16889	141
Estimated yearly thermal performance	42000	350

Table 2. Measured energy quantities for the solar heating plant.

The thermal performance of the solar heating plant was low in the start. The reason for the low thermal performance is the too low flow rate through the solar collectors. It is difficult to remove air from the solar collector field if the flow is too low and flow distribution problems/boiling problems can occur in the solar collectors if the flow is too low. The problems were solved in the middle of July 2003 by increasing the flow rate in the solar collector loop. Hereafter the thermal performance was as high as expected. Based on the measurements it is expected that the yearly thermal performance of the solar heating plant is 42000 kWh, corresponding to about 350 kWh/m².

5 Conclusions

Two solar heating systems in Aizkraukle, Latvia have been installed in the start of 2003. One of the systems is a low flow SDHW system for Aizkraukle secondary school no.2, the other system is a solar heating plant connected to the town's district heating network. The systems are equipped with monitoring equipments.

The measurements showed that both systems had start up problems with air in the solar collector loops. The air problem was solved for the solar heating plant by increasing the flow in the solar collector loop. The air problem in the SDHW system was solved by a careful installation and start up procedure.

The yearly net utilized solar energy of the SDHW system is about 150 kWh/m² and the yearly thermal performance of the solar collectors of the solar heating plant is about 350 kWh/m².

Further, the measurements showed that the SDHW system is strongly oversized. The low hot water consumption in the summer was not expected since an increased use of the sport facilities was foreseen at the time of the planning. The low hot water consumption is the main reason for the low thermal performance of the SDHW system.

The investigations elucidated that there is a need for improvements of the SDHW system.
It is recommended to stop the flow in the circulation pipe in all periods without hot water demand, to decrease the flow rate in the circulation pipe, to careful insulate the tank, the pipe connections and the heat exchangers, to secure that air is not trapped in the solar collectors and to adjust the control system so that heat can be transferred from the tank to the district heating network in periods with too high tank temperatures

The thermal performance of the solar heating plant is satisfactory.

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