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Investigations on small low flow SDHW systems with different solar pumps and solar collector loops

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Abstract

Side-by-side tests of two small low flow SDHW systems based on mantle tanks have been carried out in a laboratory test facility. The systems are identical with exception of the circulation pumps and the solar collector loops. One of the systems is equipped with a low flow SOLAR 15-65 pump from Grundfos A/S and a so-called “lifeline” solar collector loop based on a ¼” copper pipe for the hot solar collector fluid pumped from the solar collector to the mantle tank and on a 5/16” copper pipe for the cold solar collector fluid pumped from the mantle tank to the solar collector. Both the hot and the cold pipes are insulated with glass fibre and enclosed by a PVC jacket with a diameter of 38 mm. The other system is equipped with a normal circulation pump for solar heating systems, SOLAR 15-40 from Grundfos A/S and a normal solar collector loop consisting of 10/8 mm copper pipes insulated with 9 mm INSUL-TUBE insulation.

The tests were carried out with the same daily hot water consumption of 100 l/day. Measurements of the thermal performance of the systems, the volume flow rates in the solar collector loops and the energy consumption of the pumps have been carried out for a measurement period of about 4 months. The measurements show that the thermal performance of the SDHW system can be increased by about 1% by replacing the normal solar collector loop with the lifeline. The extra pump energy for the system with the lifeline and the SOLAR 15-65 pump was in the measurement period higher than the extra thermal performance for the system with the lifeline and the SOLAR 15-65 pump. Consequently, the “lifeline approach” is not justified from a thermal performance point of view.

The laboratory measurements were continued with an improved solar collector loop for the SDHW system with the SOLAR 15-65 pump. The lifeline was in July 2008 replaced with 6.35/4.85 mm copper pipes insulated with 9 mm INSUL-TUBE insulation. Further, the SOLAR 15-40 pump was replaced by a normal circulation pump UPS 15-40 from Grundfos A/S. Measurements were carried out in the period July, 2008 - April, 2009. The measurements show that the thermal performance of the SDHW system can be increased by about 7% by replacing the normal solar collector loop with the solar collector loop with the small pipes. However, the extra pump energy for the system with the small pipes and the SOLAR 15-65 pump was in the measurement period only slightly lower than the extra thermal performance. Consequently, the advantage of the SOLAR 15-65 pump and the small pipes is very limited.

1. Introduction

Small SDHW systems can with advantage be designed as schematically shown in figure 1.
Low flow SDHW systems based on vertical mantle tanks have a number of advantages compared to similar high flow SDHW systems based on vertical hot water tanks with a built in heat exchanger spiral [1]:

- The yearly thermal performance is increased by 10%-25% depending on the solar fraction.
- Lime deposits in the mantle tank are a factor of 2.5 lower than the lime deposits in a similar hot water tank with a built in heat exchanger spiral.
- Small pipe dimensions can be used in the solar collector loop. The installation can therefore be facilitated. For instance, small all-in-one solutions with two small pipes, pipe insulation and a wire for the control system can be used as a solar collector loop resulting in decreased cost of the solar heating system.

Further, if small pipes are used in the solar collector loop, the heat loss of the pipes can be reduced and the thermal performance of the system can be increased. In order to make use of small pipes in the solar collector loop, high pressure pumps are needed. Grundfos A/S has recently introduced such circulation pumps for solar heating systems on the market, for instance the SOLAR 15-65 pump. In this paper it is for small SDHW systems experimentally investigated how much the thermal performance is increased and how much the pump energy is increased by making use of small pipes and a high pressure pump in the solar collector loop.

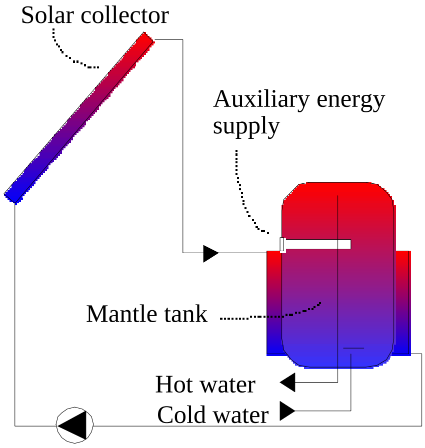

Fig. 1. Schematic illustration of SDHW system based on a mantle tank.

2. Experimental investigations

Two small low flow SDHW systems based on mantle tanks were tested side-by-side in a laboratory test facility for SDHW systems at the Technical University of Denmark. The systems are identical with exception of the solar collector loops and the circulation pumps. The most important data for the systems are shown in table 1.

One of the systems is equipped with a low flow SOLAR 15-65 pump and a so-called “lifeline” solar collector loop based on a ¼” copper pipe for the hot solar collector fluid pumped from the solar collector to the mantle tank and on a 5/16” copper pipe for the cold solar collector fluid pumped from the mantle tank to the solar collector. Both the hot and the cold pipes are insulated with glass fibre and enclosed by a PVC jacket with a diameter of 38 mm, see figure 2. The length of the lifeline in the tested system is 16 m. The other system is equipped with a normal circulation pump for solar heating systems, SOLAR 15-40, and a solar collector loop consisting of 33 m 10/8 mm copper pipes insulated with 9 mm INSUL-TUBE insulation.

The thermal characteristics of the lifeline have been investigated [2]. The heat loss coefficients of the hot and the cold pipes of the lifeline depend on the temperature difference between the hot and cold pipe and the temperature difference between the hot pipe and the ambient air temperature. For the hot pipe a typical heat loss coefficient is 0.1 W/K per m, while the heat loss coefficient of the cold pipe is typically placed in the interval from -0.4 to 0.2 W/K per m pipe. That is: In periods with high temperature differences between the hot and cold pipes the heat loss of the cold pipe is negative due to heat transfer from the hot to the cold pipe.

Fig. 2. Lifeline used as solar collector loop in one of the tested SDHW systems.

Table 1. Data for the two tested SDHW systems.

Solar collector manufacturer	Arcon Solvarme A/S
Solar collector type	ST-NA
Solar collector area	2.51 m²
Maximum collector efficiency	0.801
Collector heat loss coefficients	3,21 W/m²K and 0.013 W/m²K²
Incidence angle modifier for collector	3.6 (tangent equation)
Collector orientation	South facing
Collector tilt	45°
Mantle tank manufacturer	Nilan A/S
Mantle tank type	Danlager 1000
Domestic hot water volume	189 l
Auxiliary volume	86 l
Power of electric heating element heating the auxiliary volume to 51°C	1000 W
Outer diameter of hot water tank	0.492 m
Height/diameter ratio of hot water tank	2.1
Mantle gap	0.0115 m
Mantle height	0.395 m
Heat transfer area, mantle	0.61 m²
Water volume above upper mantle level	97 l
Mantle inlet	Top of mantle
Thickness of hot water tank wall	0.0030 m
Thickness of mantle wall	0.0025 m
Solar collector fluid	40% propylene glycol/water mixture
Location	Technical University of Denmark, Kgs. Lyngby, Denmark. Latitude: 56°N

The mantle tanks are built into a 60 x 60 x 181 cm cabinet. The space between the tank and the cabinet is filled up with PUR foam insulation. The volume flow rates in the solar collector loops are about 0.5 l/min.

3. Measured volume flow rates, pump powers, system temperatures and thermal performance

The two solar heating systems have been tested under the same test conditions in the test period March 8, 2008 – July 7, 2008: The solar radiation on the two collectors is the same and the hot water consumption and hot water consumption pattern are the same for both systems. Daily a hot water volume of 100 l, heated from 10°C to 50°C, is tapped from each tank. Hot water is drawn from the tanks at 7 am, at noon and at 7 pm in three equally sized volumes. The hot water consumption is 32.2 kWh per week.

The tapped energy, the auxiliary energy, the solar heat transferred to the heat storage, the operation time of the circulation pump, the pump energy and the heat loss from the cold and hot part of the solar collector loop are measured for each system during the whole test period. Due to problems with the monitoring system measurements were not carried out for one week during the test period.

The measured results are shown in table 2. The net utilized solar energy is the tapped energy minus the auxiliary energy transferred to the top of the tank by means of the electrical heating element. The solar fraction is the ratio between the net utilized solar energy and the tapped energy.

Table 2. Measured energy quantities in the test period March 8, 2008 – July 7, 2008.

Measured energy	Solar heating system with lifeline and SOLAR 15-65	Solar heating system with normal solar collector loop and SOLAR 15-40
Solar radiation on solar collector	3490 kWh	3490 kWh
Tapped energy	515 kWh	515 kWh
Auxiliary energy to top of tank from electrical heating element	158 kWh	163 kWh
Solar heat transferred to hot water tank	478 kWh	459 kWh
Net utilized solar energy	358 kWh	353 kWh
Solar fraction	69%	68%
Operation time of pump	913 h	873 h
Pump energy	32.6 kWh	18.3 kWh
Heat loss from solar collector loop, from collector to tank	77 kWh	94 kWh
Heat loss from solar collector loop, from tank to collector	33 kWh	76 kWh

It is seen that the thermal performance of the solar heating system with the lifeline and the SOLAR 15-65 pump is 1% higher than the thermal performance of the solar heating system with the normal solar collector loop and the SOLAR 15-40 pump.

Figure 3 shows the performance ratio, defined as the ratio between the net utilized solar energy for the solar heating system with the lifeline and the SOLAR 15-65 pump and the net utilized solar energy for the solar heating system with the normal solar collector loop and the SOLAR 15-40 pump as a function of the solar fraction for the solar heating system with the normal solar collector loop and the SOLAR 15-40 pump. Each point in the figure represents the performance ratio for one week. For instance, a point with a solar fraction of 0.85 and a performance ratio of 1.02 corresponds to a week where the thermal performance of the solar heating system with the lifeline and the SOLAR 15-65 pump is 2% higher than the thermal performance of the solar heating system with the normal solar collector loop and the SOLAR 15-40 pump and where the solar heating system with the normal solar collector loop and the SOLAR 15-40 pump covers 85% of the hot water consumption.
The extra thermal performance of the solar heating system with the lifeline and the SOLAR 15-65 pump is influenced somewhat by the solar fraction. For most weeks, the extra thermal performance is increasing for decreasing solar fraction. However, for some weeks it is the other way around. It is also seen that the pump energy for the system with the lifeline and the SOLAR 15-65 pump is higher than the pump energy for the system with the normal solar collector loop and the SOLAR 15-40 pump. The extra pump energy for the SOLAR 15-65 pump is higher than the extra net utilized solar energy for the system with the lifeline and the SOLAR 15-65 pump. Consequently, the use of the lifeline and the SOLAR 15-65 pump is not justified from a thermal performance point of view.

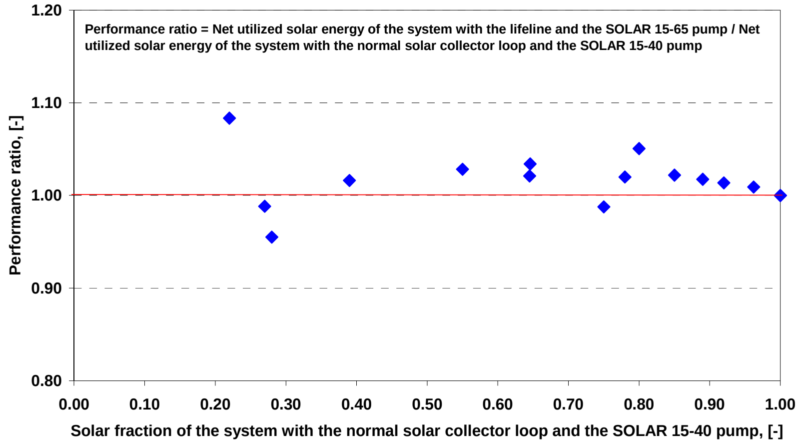

Fig. 3. Performance ratio for the solar heating system with the lifeline and the SOLAR 15-65 pump as a function of the solar fraction of the solar heating system with the normal solar collector loop and the SOLAR 15-40 pump.

Figure 4 shows the solar irradiance on the solar collectors on a cloudy day, March 28, 2008. Figure 5 shows the measured volume flow rates in the solar collector loops and the pump powers for the two systems March 28, 2008. The pumps are in operation in two periods, one from about 7:45 am to 11:45 am and one from about 12:15 pm to 15:45 pm. The volume flow rates in the solar collector loops are increasing during the operation periods. This is first of all caused by the increasing solar collector fluid temperatures. Further, relatively low volume flow rates are observed in the very start of the operation periods. This is caused by the fact that the solar collector fluid is heated to relatively high temperatures in the solar collectors during the stand by periods. When the pump is first activated the solar collector fluid with the high temperature is pumped into the pipe going downwards from the solar collector to the tank. At the same time relatively cold solar collector fluid from the mantle is pumped into the pipe going upwards from the tank to the solar collector. The density difference between the cold and the hot solar collector fluid in the two pipes is relatively large in the start-up phase due to the "overheated" solar collector fluid in the solar collectors. The pumps must overcome the pressure drops caused by these density differences. Therefore the volume flow rates are especially low in the start-up phase. It is also noticed that the pump powers are decreasing during the operation period. This is especially true for the SOLAR 15-65 pump.

Figure 6 shows the power supply from the solar collector fluid to the tanks of the two systems during March 28, 2008. There are not large differences between the two systems.

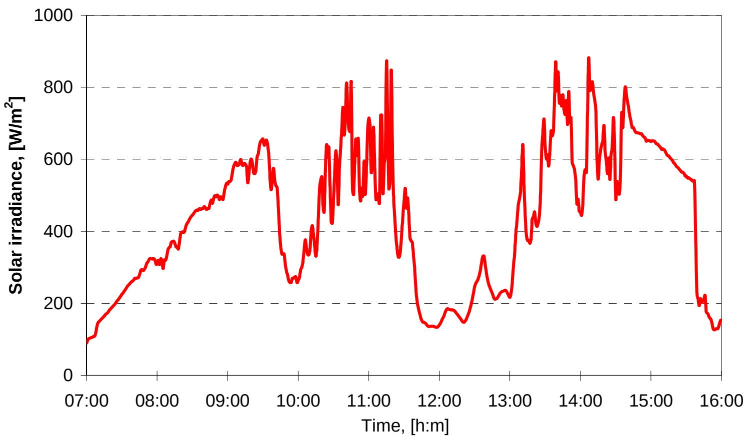

Fig. 4. Total solar irradiance on solar collectors, March 28, 2008.

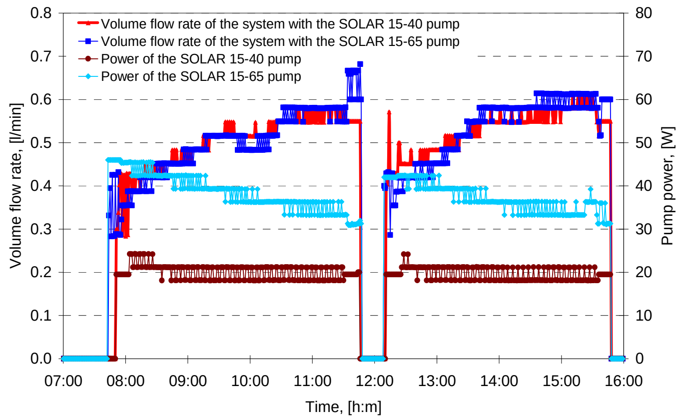

Fig. 5. Measured volume flow rates and pump powers for the two systems March 28, 2008.

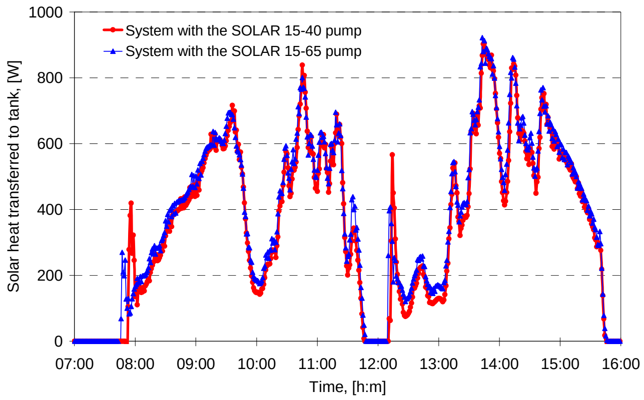

Fig. 6. Solar heat transferred to the tanks of the systems March 28, 2008.

Figures 7 and 8 show the measured solar collector fluid temperatures in the two systems March 28. It is seen that the difference between the heat loss from the hot pipes for the two systems is small and that the heat loss from the cold pipe in the system with the lifeline is small compared to the heat loss from the cold pipe for the other system. The small heat loss of the cold pipe results in a relatively high inlet temperature to the solar collector and thereby in a somewhat reduced collector efficiency. Therefore the thermal advantage by the low heat loss from the cold pipe of the lifeline is limited.

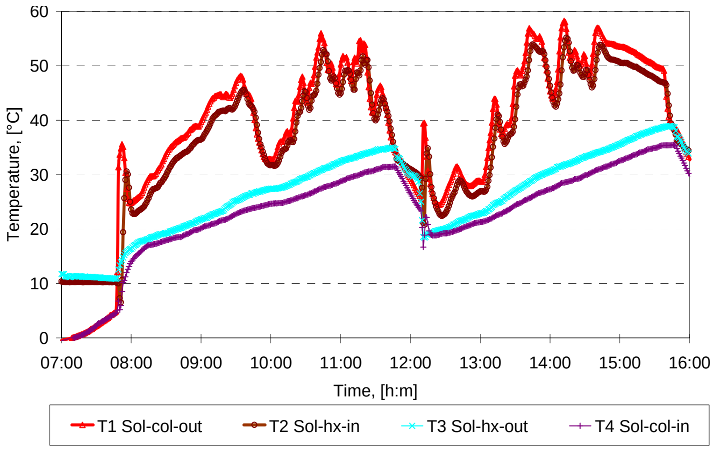

Fig. 7. Measured solar collector fluid temperatures in the solar collector loop for the system with the normal solar collector loop and the SOLAR 15-40 pump March 28, 2008.

Figure 9 shows for March 28 the pump powers and volume flow rates in the solar collector loops for the two systems as a function of the solar collector fluid temperature passing the pumps. The volume flow rates are increasing and the pump powers are decreasing for increasing temperatures. The volume flow rates are almost the same for the two systems. The volume flow rates varies from about 0.3 to 0.6 l/min and the pump powers are about 20 W for the SOLAR 15-40 pump and varies from about 45 to 30 W for the SOLAR 15-65 pump.

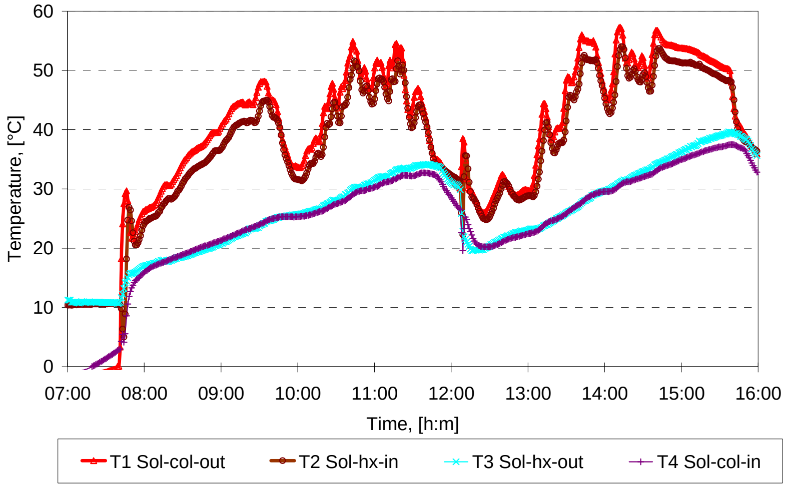

Fig. 8. Measured solar collector fluid temperatures in the solar collector loop for the system with the lifeline and the SOLAR 15-65 pump March 28, 2008.

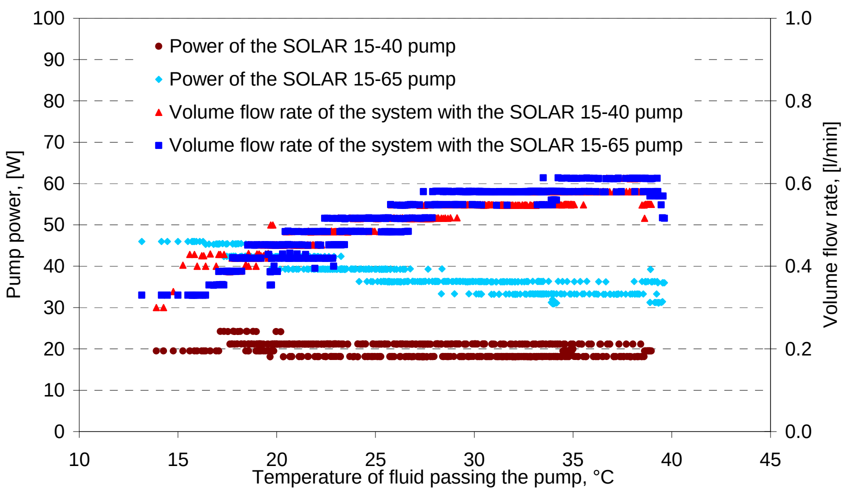

Fig. 9. Measured pump powers and volume flow rates as a function of the temperature of the solar collector fluid leaving the mantle for the two systems March 28, 2008.

4. Investigations with separate copper pipes in the solar collector loop

The measurements showed that the used lifeline has poor thermal characteristics. The heat loss of the hot pipe is not much lower than the heat loss of the hot 10/8 mm pipe, while the cold pipe in the lifeline has a lower heat loss than the cold 10/8 mm pipe. The decreased pipe heat loss will however only slightly increase the thermal performance of the solar heating system.

Therefore, in July 2008 the 16 m lifeline was replaced by 33 m 6.35/4.85 mm copper pipes with 9 mm INSUL-TUBE insulation. At the same time the positions of the pumps were changed from the cold side of the solar collector loop to the hot side of the loop. That is: The solar collector fluid is now passing the pumps just before the fluid enters the mantles. In this way the pump power which heats up the fluid is utilized in a better way than if the fluid is heated before it enters the solar collectors. Further, the SOLAR 15-40 pump was replaced by a normal circulation pump, type UPS 15-40, since this is the circulation pump used in most Danish marketed solar heating systems today.

The results of the measurements for the period July 30 - April 12, 2009 are shown in table 3. Due to problems with the monitoring equipment only measurements for 26 weeks are included.

Table 3. Measured energy quantities in the test period July 30 - April 12, 2009.

Measured energy	Solar heating system with 6.35/4.85 mm copper pipes and SOLAR 15-65	Solar heating system with normal solar collector loop and UPS 15-40
Solar radiation on solar collector	1167 kWh	1167 kWh
Tapped energy	839 kWh	839 kWh
Auxiliary energy to top of tank from electrical heating element	569 kWh	587 kWh
Solar heat transferred to hot water tank	407 kWh	391 kWh
Net utilized solar energy	270 kWh	252 kWh
Solar fraction	32 %	30%
Operation time of pump	904 h	832 h
Pump energy	35 kWh	19 kWh

The thermal performance of the system with the 6.35/4.85 mm copper pipes and the SOLAR 15-65 pump is 7% higher than the thermal performance of the solar heating system with the normal solar collector loop and the UPS 15-40 pump. The extra pump energy for the SOLAR 15-65 pump is now lower than the extra net utilized solar energy for the system with the SOLAR 15-65 pump. However, the advantage of the SOLAR 15-65 pump together with the small separate pipes in the solar collector loop is very limited.

5. Conclusion

Side-by-side laboratory tests for two small low flow SDHW systems have shown that a solar collector loop based on a marketed lifeline with a SOLAR 15-65 pump has no thermal advantage compared to a solar collector loop based on normal pipes and a normal solar circulation pump. The reason is the poor thermal characteristics of the lifeline.

Further, measurements have shown that a SDHW system with a solar collector loop based on small separate pipes and the SOLAR 15-65 pump performs 7% better than a similar SDHW system based on a normal solar collector loop and a UPS 15-40 pump. However, the extra pump energy for the system with the small pipes and the SOLAR 15-65 pump is only slightly lower than the extra thermal performance. Consequently, the advantage of the SOLAR 15-65 pump and the small pipes is very limited.

Furthermore, measurements have shown that the volume flow rates in the solar collector loops as well as the pump power of the SOLAR 15-65 pump are strongly influenced by the operation conditions, and that the pump power of the SOLAR 15-40 pump is constant regardless of the operation conditions.

Based on the findings it is recommended to start work to develop a flexible solar collector loop including a cold and a hot pipe with limited heat transfer from the hot to the cold pipe. A high pressure pump with a relatively low pump power would also be very attractive.

References

[1] S. Furbo (1990). Small Low Flow DHW Solar Heating Systems – Status. Thermal Insulation Laboratory, Technical University of Denmark, report no. 90-13.

[2] S. Furbo (1993). Tests of the components of the Solar Boiler system from Thermo Dynamics Ltd. Thermal Insulation Laboratory, Technical University of Denmark, report no. 93-20.

Side-by-side laboratory tests of two small low flow SDHW systems have been carried out. The systems are identical with exception of the circulation pumps and the solar collector loops. One system is based on a SOLAR 15-65 pump from Grundfos A/S and a solar collector loop with the hot and cold pipe enclosed by a PVC jacket or 6.35/4.85 mm copper pipes insulated with 9 mm INSUL-TUBE insulation. The other system is based on a normal circulation pump for solar heating systems, SOLAR 15-40 from Grundfos A/S and a solar collector loop consisting of 10/8 mm copper pipes insulated with 9 mm INSUL-TUBE insulation.

The measurements showed that the advantage of the SOLAR 15-65 pump and the small pipes is very limited.

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