Long term test results from a Latent Heat Storage developed for a Solar Heating and Cooling System

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Abstract

In solar thermal installations, full annual utilisation is preferable. During the cold season, solar heat serves for space heating. During the warm season, solar heat can be converted into useful cold by means of sorption cooling. In the case that low temperature heating and cooling facilities like floor/wall heating systems or activated ceilings are applied for heating and cooling, a low-temperature heat storage using the latent heat of phase change materials (PCM) can be used to significantly improve the performance of the system in the cooling mode and in the heating mode as well.

A storage with about 2.4 tonnes of $CaCl_2 \cdot 6H_2O$ as PCM and capillary tubes as heat exchanger was built in fall 2006. The storage consists of two modules with a total volume of 1.6 m³ and has a design storage capacity of 120 kWh in the temperature range between 25 °C and 33 °C. The storage is integrated into a system for solar heating and cooling of an institute building in Garching, Germany. This paper reports on standalone tests and long term results of the storage during system operation from 2007 until 2010.

1. Introduction

In solar thermal installations, both solar cooling and solar heating can be provided synergistically, yielding a complete annual utilisation. During the cold season, solar heat serves for space heating. During the warm season, solar heat can be converted into useful cold by means of sorption cooling. A favourable situation is given when low temperature heating and cooling facilities, e.g. floor or wall heating systems or activated ceilings, are applied for heating and cooling. During heating operation, a low temperature latent heat storage can be used to balance the heat generation by the solar system and the supply to the heating system. Thus, a low operating temperature of the solar thermal system is accomplished yielding efficient operation with optimum solar gain.

In the cooling mode, the same storage is used in combination with a dry cooling tower to absorb/reject the waste heat in order to replace a wet cooling tower. By that means heat rejection of the chiller is shifted partly to periods with lower ambient temperatures, i.e. night time, or to off-peak hours.

2. System Concept

In conventional absorption cooling installations, wet cooling towers designed for a coolant supply/return temperature 27/35 °C are applied. To use a dry air-cooler, cooling water temperatures have to be increased to 40/45 °C. As a consequence of the increase of the cooling water temperature, the temperature level of the driving heat supplied to the regenerator of the absorption chiller has to be increased accordingly.

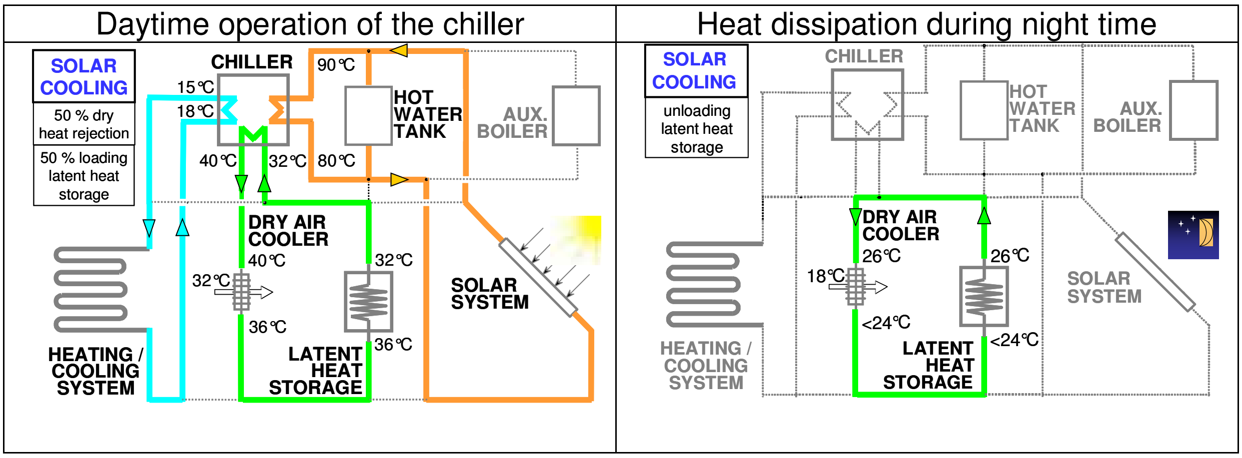

Fig. 1. System scheme of the solar cooling installation supported by latent heat storage.

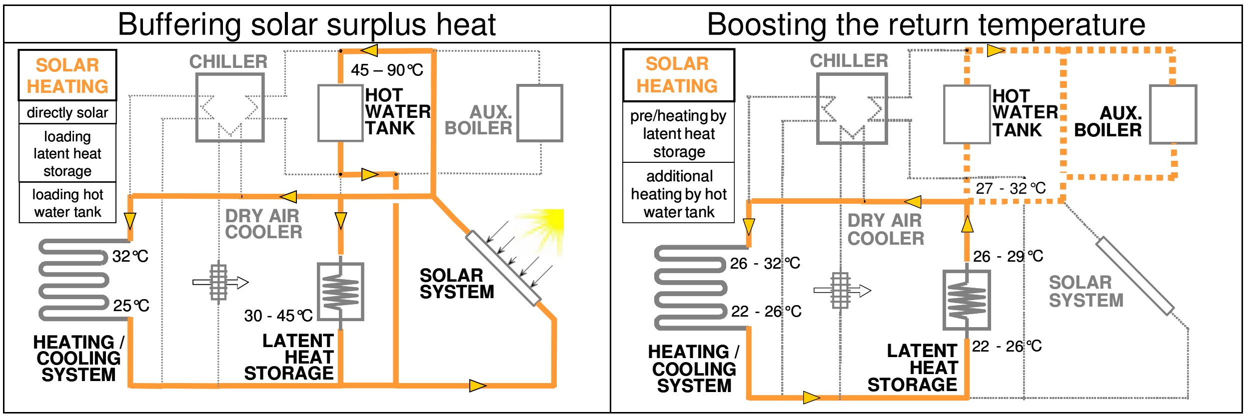

Fig. 2. System scheme for solar heating with latent heat storage

By integrating a heat storage into the heat rejection system of the absorption chiller, a part of the reject heat can be buffered during peak load operation of the chiller, allowing coolant temperatures of 32/40 °C. During off-peak operation or at night time when lower ambient temperatures are available, the stored reject heat can be discharged. As a consequence of the reduced coolant temperature arising from the integration of the latent heat storage, lower temperatures of the driving solar heat are feasible to operate the absorption chiller. Thus a higher solar gain is obtained for a given size of the solar collector system. A detailed analysis of the overall system design has been presented earlier [1, 2].

During the heating season, the latent heat storage buffers the solar surplus heat and balances the heat supply to the consumer by boosting the return temperature of the heating system (see Figure 2). Thus, a low operating temperature of the solar thermal system is accomplished yielding efficient operation with optimum solar gain.

Simplified system configurations for cooling and heating operation are given in Figure1 and Figure 2.

3. Pilot Installation

Within the framework of the German "Solarthermie 2000plus" program, a pilot installation of the solar heating and cooling system has been set up [3-5].

With respect to the solar cooling power of about 10 kW, a waste heat storage with a capacity of about 120 kWh is required in order to cover 50 % of the daily reject heat output of the chiller. The rest of the reject heat is directly transferred to the ambient by means of a dry air cooler, which operates with 36/40 °C cooling water temperature under peak load conditions, as illustrated in Figure 1. Therefore, the design of the latent heat storage has been based on 36/32 °C cooling water supply/return temperature.

Apart from the solar cooling mode, during the heating season the system serves for solar-assisted heating. Assuming a solar insulation of 500 W/m^2 for a duration of 6 hours again a heat storage capacity of about 120 kWh is required to absorb the solar gain of the 40 m^2 solar collector field. The solar heat has to be stored above the return temperature of the building floor heating system, which is controlled in dependence of the ambient temperature. Under moderate winter heating conditions, the heating system return temperature typically ranges from 22 °C to 26 °C. Due to the fact that heat has to be transferred from the heat storage to the heating system, phase transition of the PCM has to take place above the temperature level of the heating system.

4. Latent Heat Storage Design

For the given application in a solar heating and cooling system, heat has to be stored in a very narrow temperature range in order to fulfil both tasks: support of the heat rejection of the chiller requires a phase change temperature below 32 °C, and contribution to the heating of the building a phase change temperatures above 26 °C.

Due to this limitation of the available temperature swing, the heat storage has been designed as latent heat storage. According to its melting temperature in the range of 28 – 29 °C the salt hydrate calcium chloride hexahydrate ($CaCl_2•6H_2O$) has been chosen as phase change material (PCM), providing a heat capacity of about 150 J/g or 240 J/L between 22 °C and 36 °C. This value of the specific storage capacity comprises both sensible and latent heat. Of course the dominating portion is to be attributed to the latent part.

Within the project a commercial capillary tube system commonly used for wall heating installations has been applied as heat exchanger in the latent heat storage. Because of the high storage density of the PCM and its low thermal conductivity, a distance between the capillaries of only a few centimetres has been chosen.

To reach 120 kWh heat storage capacity, two storage modules with a volume of 800 L each have been designed and constructed. The capillary tube heat exchanger has been properly configured in order to fully activate the entire storage volume. The heat exchanger has finally been immersed in a Polyethylene tank and hermetically sealed in order to avoid uptake of humidity from the ambient air.

5. Results

5.1. Long term stability of the PCM storage

Between 2007 and 2010 recurring measurements of loading and unloading the storage were carried out to determine long term effects on the PCM. These measurements showed no degradation of thermal power or capacity (see Figure 3), confirming the assumption that the separation of the PCM could be prevented successfully.

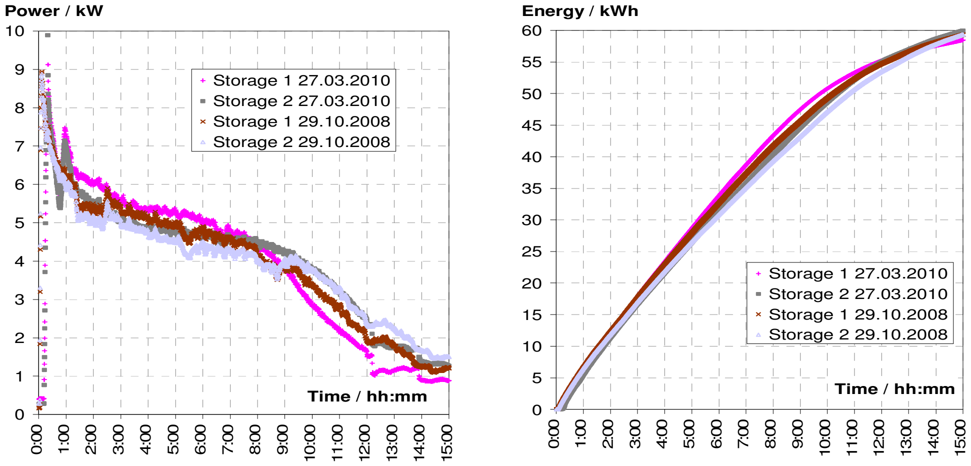

Fig. 3. Power and the stored energy of the two PCM storage modules during loading with a heat carrier supply temperature of 36 °C and a flow rate of 1.5 m^3/h.

5.2 Long term operation

In the following the long term operation of the latent heat storage as part of the solar heating and cooling system is described. Figure 4 shows the charging and discharging cycles of the latent heat storage during summer and winter operation in 2008 and 2009 (data for 2009 in the following text in brackets), respectively. In total 293 (223) charging and discharging cycles have been performed. During the heating season a total of 6478 (3922) kWh solar heat has been stored, whereof 5741 (3323) kWh could be discharged, resulting in an overall storage efficiency of 88,6% for 2008 and 84,7% for 2009. In the cooling period 2105 (2053) kWh reject heat of the absorption chiller have been stored. In this case with close temporal coherence of loading and unloading a storage efficiency of 96,6% (85,4%) has been accomplished..

Figure 4 furthermore illustrates the large impact of the weather situation on the utilization of the latent heat storage: Due to mild and sunny weather in spring 2008 rather large amounts of heat have been processed whereas a substantially lower utilization of the storage has been accomplished in winter

2008/09.

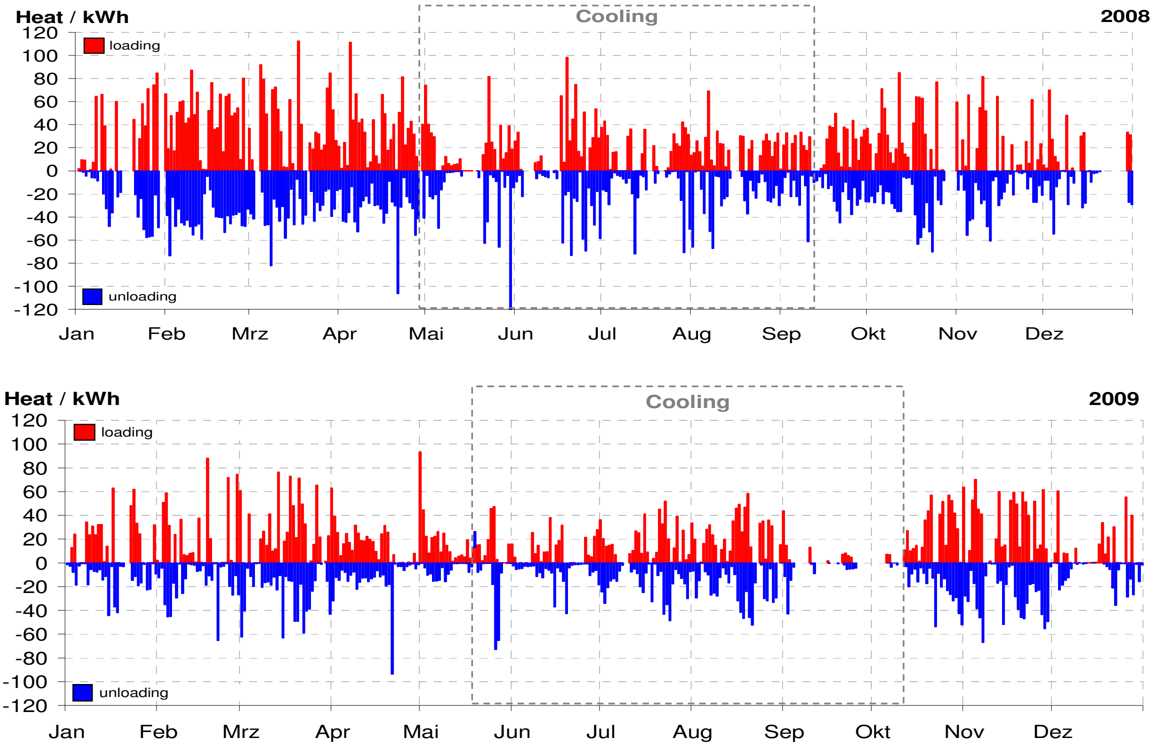

Fig. 4. Loading and unloading cycles of the PCM storage

5.3 Charge/discharge management of the PCM storage

In order to operate a PCM storage as efficient part of a heating or cooling system, precise information about the actual energy content of the storage is essential. Due to the fact that a metering method for the thermal content of a latent heat storage is still a matter of development, up to now the potential for efficient charging and discharging of the storage could not be fully exploited. As a first attempt, different approaches using a heat meter to indicate the actual state of charge had only little success due to the small temperature difference of the heat carrier between storage inlet and outlet and the resulting inaccuracy of the control. To integrate the storage into the solar heating and cooling system despite the missing charge control, for the moment different temperature criteria are used to achieve a rough estimate of the actual state of charge. The development of a more precise metering procedure is ongoing.

Figure 5 shows the transferred heat for a series of loading and unloading cycles of the mentioned PCM storage during solar cooling operation in summer 2008 an 2009, respectively. In cooling mode complete discharge of the accumulated heat during the following night is strived for. Yet, due to the imperfect charge control a substantial mismatch between loading and unloading of the storage occurrred in 2008. Finally, by improving the control strategy in 2009 the daily disbalance of the heat storage has been minimized.

As a second conclusion from Figure 5, it can be stated that the storage allows for efficient mid-term storage, e.g. storage periods of some days, without substantial heat loss: A prove is given by the period May 23 to 30, 2008, when the solar gain accumulated during 8 days is almost completely extracted on two days only.

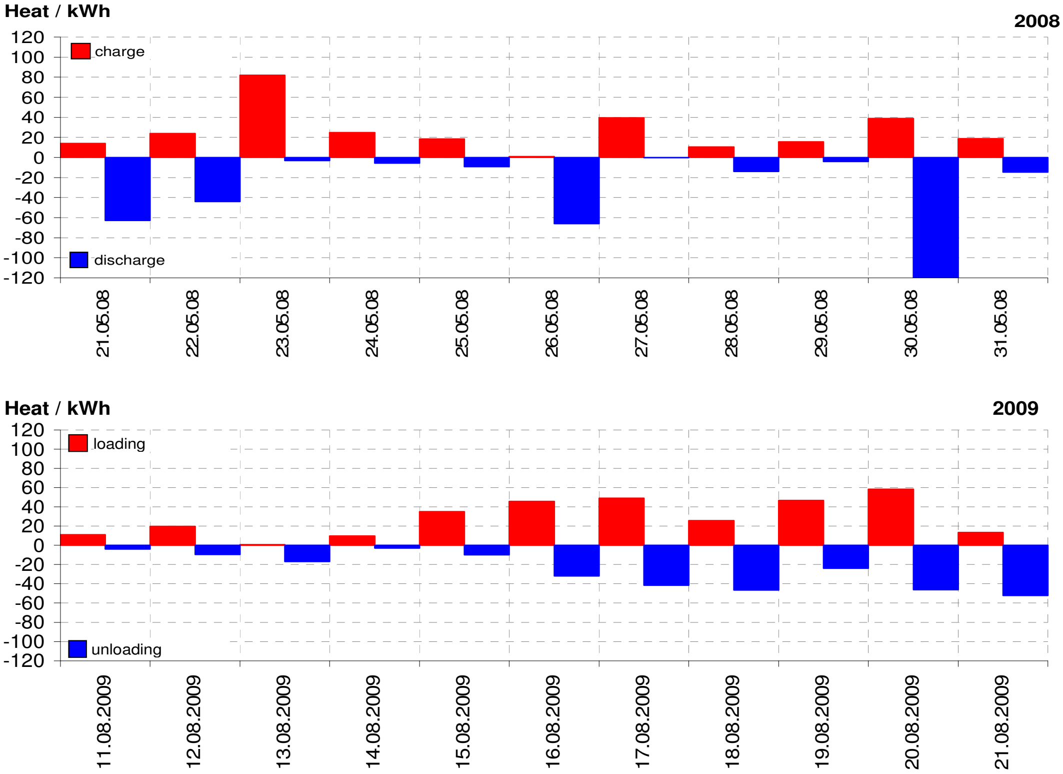

Fig. 5. Loading / unloading cycles of the PCM Storage 2008 / 2009

5.4 Solar heating

In the following paragraph the collected measurement data from solar heating is presented for the periods January – April (May) 2008 and 2009 (data in the text in brackets), respectively. As indicated earlier, heat demand and solar gain are strongly dependent on the ambient conditions.

In 2008 a substantially higher level of insolation compared to 2009 allowed for a higher solar heat accumulation accompanied by a lower building heat demand. Consequently, a monthly solar fraction of 24 % to 85 % was reached in the period Jan – March 2008, whereas under severe winter condition in January and February 2009 the solar coverage was limited to 15 to 18 % only. In the transitional period March/April 2008 and April/May 2009 almost fully solar coverage has been reached.

For the whole winter periods 2008 and 2009 as shown in Fig. 8 and 9 solar fractions of 48 % and 33 % have been achieved.

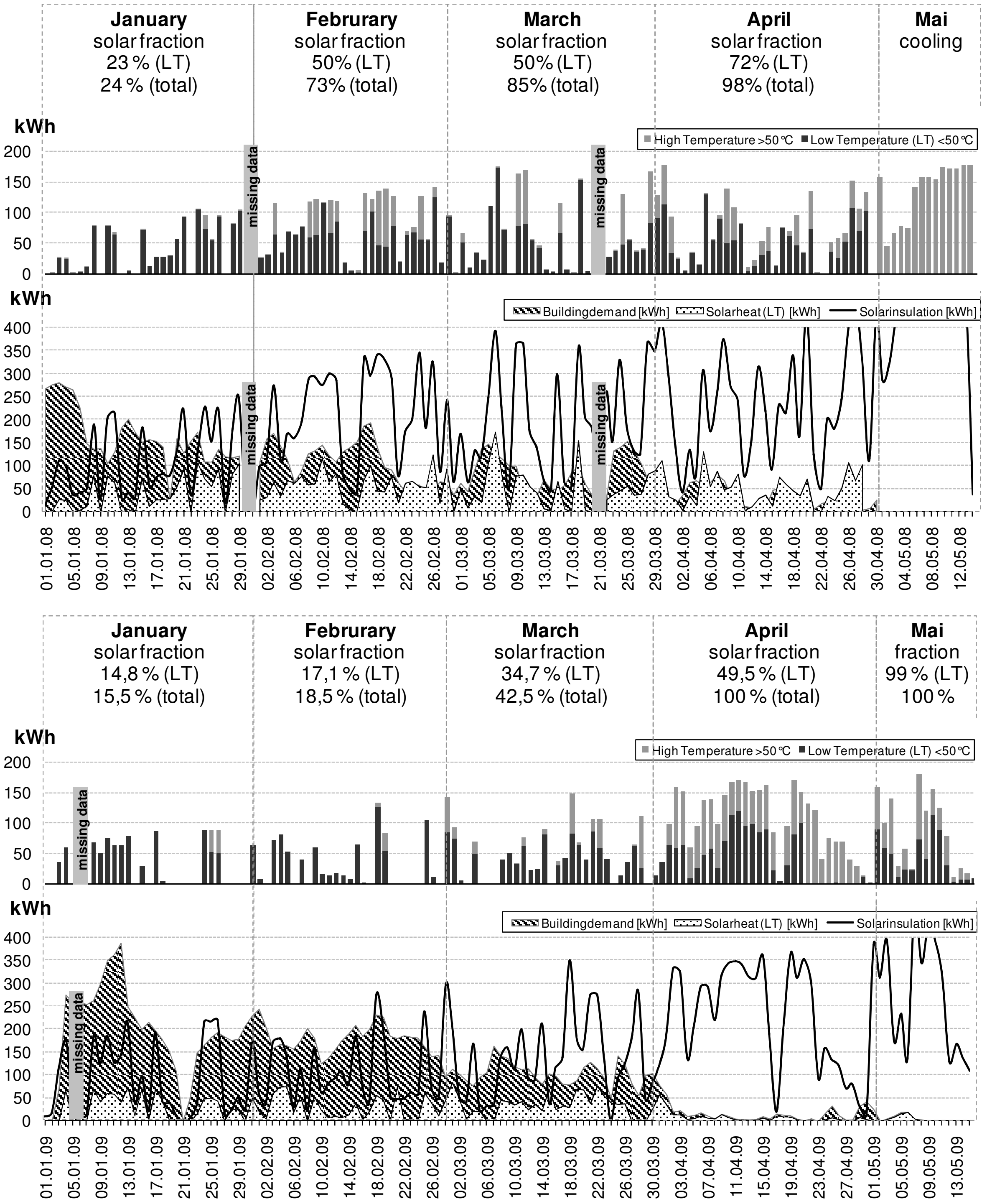

Fig. 7. Measurement data from solar heating period 2008 (top) and 2009 (bottom)

All data of the solar fraction given above refer to the total amount of solar heat supplied to the building. These results by far exceed the performance of conventional large-scale solar installations.

Pre-requisite for the obtained efficiency of the solar system is the operation at moderate collector temperatures stabilized by means of the low-temperature latent heat storage. As a consequence, the major part of the solar heat supplied to the building passes through the low-temperature (LT) heat storage and only minor parts of the heat are generated at higher temperature levels, as given by the monthly data for the total heat supply to the building (total) and the contribution of the latent heat storage (LT).

6. Conclusion

A solar heating and cooling system with absorption chiller and latent heat storage has been operated for more than three years with high energetic efficiency and only minimal maintenance effort. In recurring measurements from 2007 until now no aging effects of the phase change material (PCM) used in the latent heat storage could be observed.

Due to the implemented latent heat storage solar cooling with a dry cooling tower has been accomplished during the whole cooling period independently from ambient temperatures. In the heating periods an average solar fraction of 48% in 2008 and 33% in 2009 has been achieved owing to the reduced collector temperature stabilized by the latent heat storage.

With regard to optimized utilization of the latent heat storage in solar cooling mode, lowest ambient temperatures during the early morning hours should be used for unloading of the storage. Thus, a precise information about the actual heat content of the storage is required. Up to now rather complex control strategies have been implemented for improving the system performance.

Aiming at series-production and wider distribution of the storage, in Oct 2009 a follow-up project for further development of the solar heating and cooling system has been started . Main focus are the thermal design and construction of the heat exchanger and the liquid container and auxiliary components, e.g. the metering system for the thermal content and a anti-separation mechanism.

ACKNOWLEDGMENTS

The project is supported by funds of the German Federal Ministry of Environment (BMU) under contract number 0329605D.

References

[1] C.Schweigler, S.Hiebler, C.Keil, H.Köbel, C.Kren, H.Mehling, (Jan. 2007). Low temperature Heat Storage for Solar Heating and Cooling Applications. *ASHRAE Transactions*, ASHRAE Winter-Meeting, Dallas, USA.

[2] S.Hiebler, H.Mehling, M.Helm, C.Schweigler, (Nov 2009) Latent Heat Storage with melting temperature 29 °C supporting a Solar Heating and Cooling system. Effstock, Stockholm, Sweden

[3] C.Schweigler, A.Costa, M.Högenauer-Lego, M.Harm, F.Ziegler, Absorptionskaltwassersatz zur solaren Kühlung mit 10 kW Kälteleistung. *Ki Luft- und Kältetechnik*, (4/2002) 201-205.

[4] F.Storkenmaier, M.Harm, C.Schweigler, F.Ziegler, P.Kohlenbach, T.Sengewald, Small-capacity LiBr Absorption Chiller for Solar Cooling or Waste-Heat driven Cooling. *Proc. of the 30th International Congress of Refrigeration*, Sept. 2003, Washington, USA.

[5] A.Kühn, M.Harm, P.Kohlenbach, S.Petersen, C.Schweigler, F.Ziegler, Betriebsverhalten einer 10 kW Absorptionskälteanlage für die solare Kühlung. *Ki Luft- und Kältetechnik*, (41. Jahrgang) 7/2005, S. 263-266.