IN-SITU INVESTIGATION OF A DOMESTIC SOLAR/HEAT PUMP HEATING SYSTEM IN A ONE-FAMILY HOUSE

Matthias Sonnleitner, Christoph Trinkl, Wilfried Zörner

Centre of Excellence for Renewable Energy Research, Ingolstadt University of Applied Sciences, Esplanade 10, D-85049 Ingolstadt (Germany), Phone +49 841 9348 372,
Email: christoph.trinkl@haw-ingolstadt.de

Abstract

A detailed in-situ analysis of a domestic solar/heat pump heating system, combining solar-thermal collectors, heat pump and a ground-coupled water/ice latent heat storage tank is presented. In an industrial joint research project with *Ratiotherm Heizung + Solartechnik GmbH & Co. KG*, Dollnstein (Germany), a one-family house served as a field-testing building and was equipped with the solar/heat pump system. Using measurement equipment in the system, a detailed scientific investigation was carried out by the *Centre of Excellence for Renewable Energy Research* at *Ingolstadt University*. Measurements regarding the overall system performance, the solar system, the heat pump, the buffer storage tank and the latent heat storage tank were carried out. Furthermore, within the analysis the overall system functionality and operational difficulties with a focus on practical operation under field-testing conditions were identified and evaluated, e.g. in hydraulics and supervisory control. Finally, the importance of field tests for -often complex- solar/heat pump heating systems in comparison to standardised laboratory test sequences could be emphasised.

1. Introduction and Background

The combination of solar-thermal collectors and heat pumps provides interesting possibilities for innovative and energy efficient heating systems with a high fraction of solar energy. Due to the accelerating pace of climate change and the rising cost of limited fossil resources, they are gaining more and more importance. Already in the 1970s, solar/heat pump heating systems were investigated and promising results were achieved in research projects, as for example described and evaluated by Trinkl et al. [1]. Advantages of these systems are considered to be an improvement of solar fraction (i.e. by extended solar collector utilisation time and enhanced collector efficiency) and therewith a reduction of electric energy demand for the heat pump by management of the source and sink temperatures. Furthermore, favourable system approaches provide a highly flexible application due to their independence of a typically large area for heat pump ground collectors as a heat source, which often has restricted heat pump distribution. Hence, several producers of heating systems have introduced solar/heat pump heating systems into the market in the last few years with significant differences in conception, construction and functionality, as for example shown by Müller et al. [2] in a market survey. Typically, solar/heat pump heating systems are rather complex heating systems. The functionality of these systems can lead to special operating conditions which significantly differ from conditions in standard solar systems, e.g. low collector temperatures below the dew point. Except for project results from the 1970s and 1980s and results published by Leibfried et al. [3], very limited experiences or measurement data are available from field test measurements under practical conditions for solar/heat pump heating systems with glazed collectors.

The *CENTRE OF EXCELLENCE FOR RENEWABLE ENERGY RESEARCH* at *Ingolstadt University* has carried out research and development in the field of solar/heat pump heating systems for several years. In an industrial joint research project with the industrial partner *Ratiotherm Heizung + Solartechnik GmbH & Co. KG,* Dollnstein (Germany), a solar/heat pump heating system combining a brine heat pump and solar-thermal collectors connected with a water/ice latent heat storage tank, was initially developed [4]. Within this project the conception of the system layout [5], the development of optimised control strategies and an investigation of the system performance in simulations [6,7] were carried out. Additionally, the water/ice latent heat storage tank including suitable heat exchangers and storage tank was developed [8]. In a subsequent research project in cooperation with the industrial partners *Ratiotherm Heizung + Solartechnik GmbH & Co. KG*, Dollnstein (Germany), *Viessmann Werke GmbH & Co. KG*, Allendorf *(Germany)* and the research partner *Solar-Institut Jülich* (Germany), further work on system and component basis was carried out. The function and performance of the water/ice latent heat storage tank was for instance proofed in laboratory investigations [9]. In order to gain more experience and to optimise the overall system under operating conditions, a field test with the solar/heat pump heating system including in-situ measurements was initiated. Therefore, a one-family house was equipped with the innovative domestic heating system (figure 1), combining solar-thermal collectors, a heat pump and a water/ice latent heat storage tank including measurement equipment for a detailed scientific in-

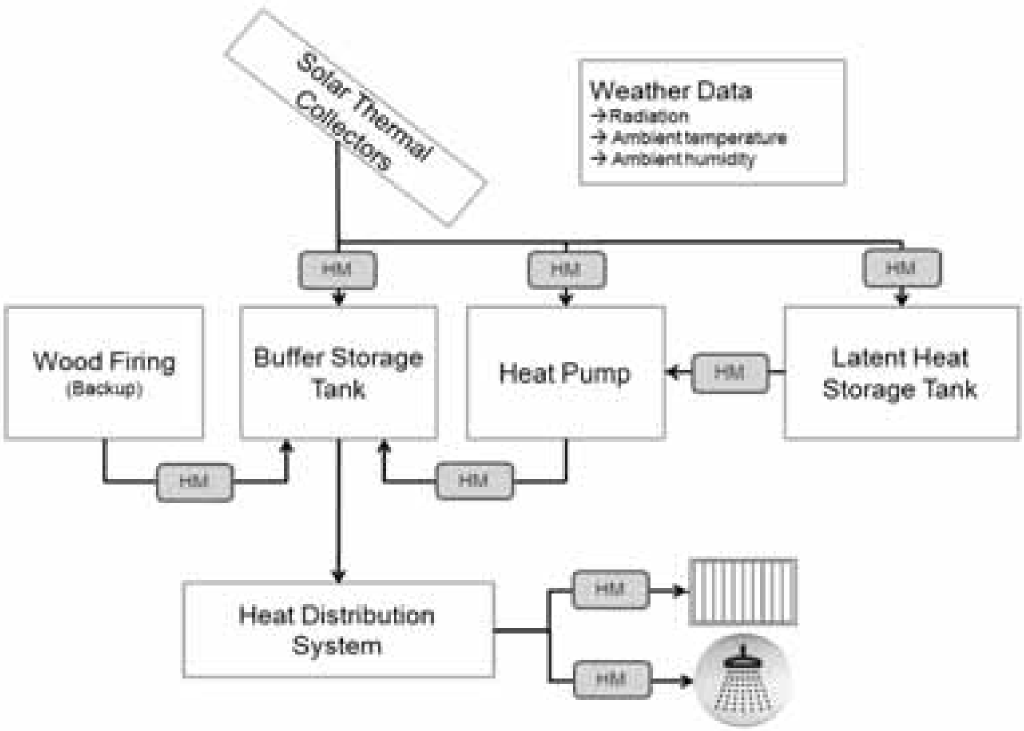

Figure 1: Schematic of the heating system and measurement equipment (HM: heat metre)

vestigation [9,10]. The in-situ investigation applies to single components as well as to the overall functionality and resultant operational challenges.

The research work shown in the following was carried out in close co-operation with the industrial partner *Ratiotherm Heizung + Solartechnik* and was partially funded by the *German Ministry for Education and Research*. It is carried out within the framework of Task 44 “Solar and Heat Pump Systems” in the *Solar Heating and Cooling Programme* of the *International Energy Agency*.

2. System configuration and in-situ measurements

The field-testing building has 277 m² living area and a heating demand of about 70 kWh/(m²a). It is located in Southern Germany near Crailsheim and is inhabited by three persons. A buffer storage tank with a volume of about 1,000 litres, which is connected to a heat distribution system, is situated in the basement boiler room. Additionally to this buffer storage tank, an uninsulated water/ice latent heat storage tank with a volume of about 7,150 litres is located outside the building in the ground. The 45 m² collector array on the southwest roof of the building supplies the buffer storage tank with solar-thermal energy (figure 1). By using heat metres, the heat flows in the system can be measured continuously and accessed via Internet. Thus, a detailed monitoring of the system is possible regarding the overall system, the latent heat storage tank, the buffer storage tank and the heat pump.

3. Water/ice latent heat storage tank

The water/ice latent heat storage tank is used as heat source for the heat pump and is regenerated by solar-thermal energy. The discharging process of the water/ice latent heat storage tank can be subdivided in three sections (figure 2): Initially, the heat pump extracts sensible heat from the liquid store (section 1). When reaching 0°C, the process of freezing begins, i.e. phase change takes place. Within this phase the temperature remains constant and the latent heat (334 kJ/kg) is extracted (section 2). It should be noted that phase change does not occur at the same time in the entire store, but starts growing onwards from the cold heat exchanger surfaces. As soon as the whole storage medium is frozen, the temperature drops below 0°C (section 3). The process is fully reversible, so that store charging works reversely and solar-thermal energy melts the latent heat storage tank. As the charging and discharging processes are not completely homogeneous in the store and are also accompanied with volume change, these particular operating conditions during phase change have to be considered in heat exchanger as well as in storage tank design.

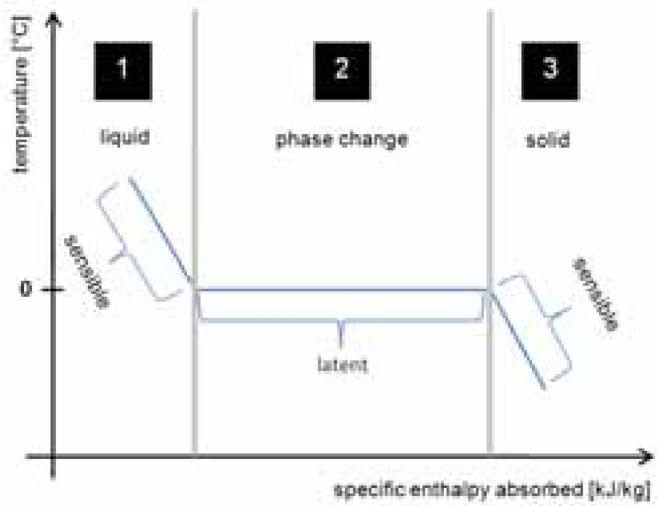

Figure 2: Diagram of store discharging with phase change

In the field-testing system, the phase change can be illustrated by the temperature supplied from the water/ice latent heat storage tank to the heat pump extraction circuit (heat pump source-side). Figure 3 shows the freezing process subdivided into the three mentioned phases. It should be considered that a representative latent heat storage tank temperature is only obtained when the heat pump is operating. While the heat pump is not operating, the ambient temperature induces a rise of temperature at the sensor. High temperatures, however, display a charging and regeneration of the storage tank with solar-thermal energy.

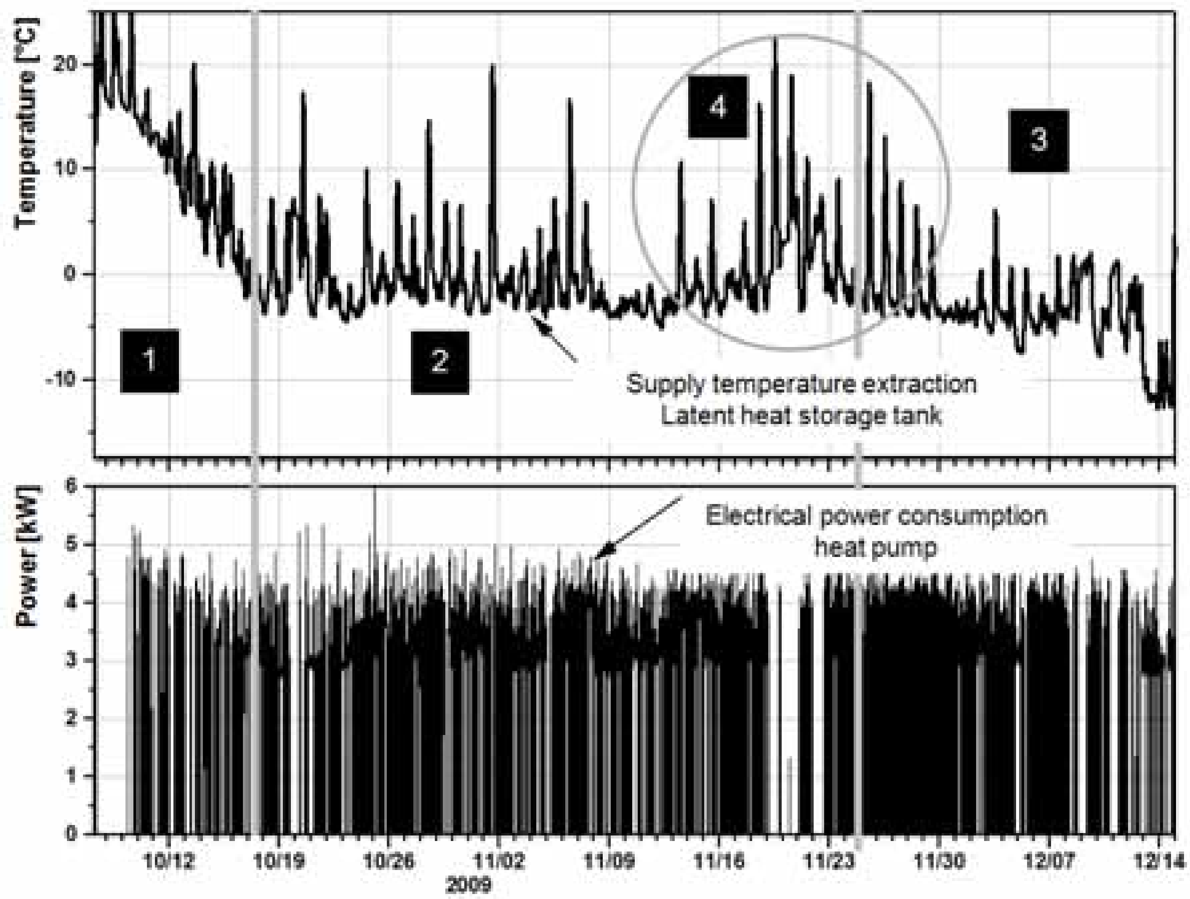

Figure 3: Behaviour of the latent heat storage tank

From beginning to mid of October 2009 the storage tank temperature decreased from 20°C to 0°C as shown in section (1). From this day on, the water/ice latent heat storage tank is in the state of phase change from liquid to solid with a supply flow temperature of about 0°C (2). Mid of November (4), the temperature increased and the water/ice latent heat storage tank was partially regenerated, but did obviously not melt completely. This process took several days with high solar insolation of 750…800 W/m². Finally, the supply flow temperature dropped below 0°C in the beginning of December 2009 (3). This indicates that the phase change was finished and the storage medium was completely frozen.

To analyse the influence of the water/ice latent heat storage tank on the surrounding soil temperature, sensors are positioned around the tank (figure 4). As there is no insulation around the storage tank, the temperature at the outer wall (figure 5, upper graph) shows the same behaviour as the temperature of the storage medium (cf. figure 3). The temperature dropped to 0°C until end of October (section 1) and remains at this level during phase change (2). In section (1) and (2), an influence of the positive ambient temperature cannot be seen. Starting from mid-December, the soil temperature at the outer wall drops and finally reaches a level of approximately -5°C (3).

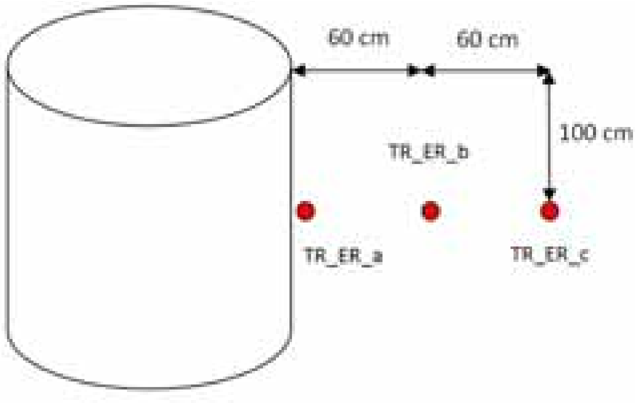

Figure 4: Positioning of the temperature sensors around the water/ice latent heat storage tank

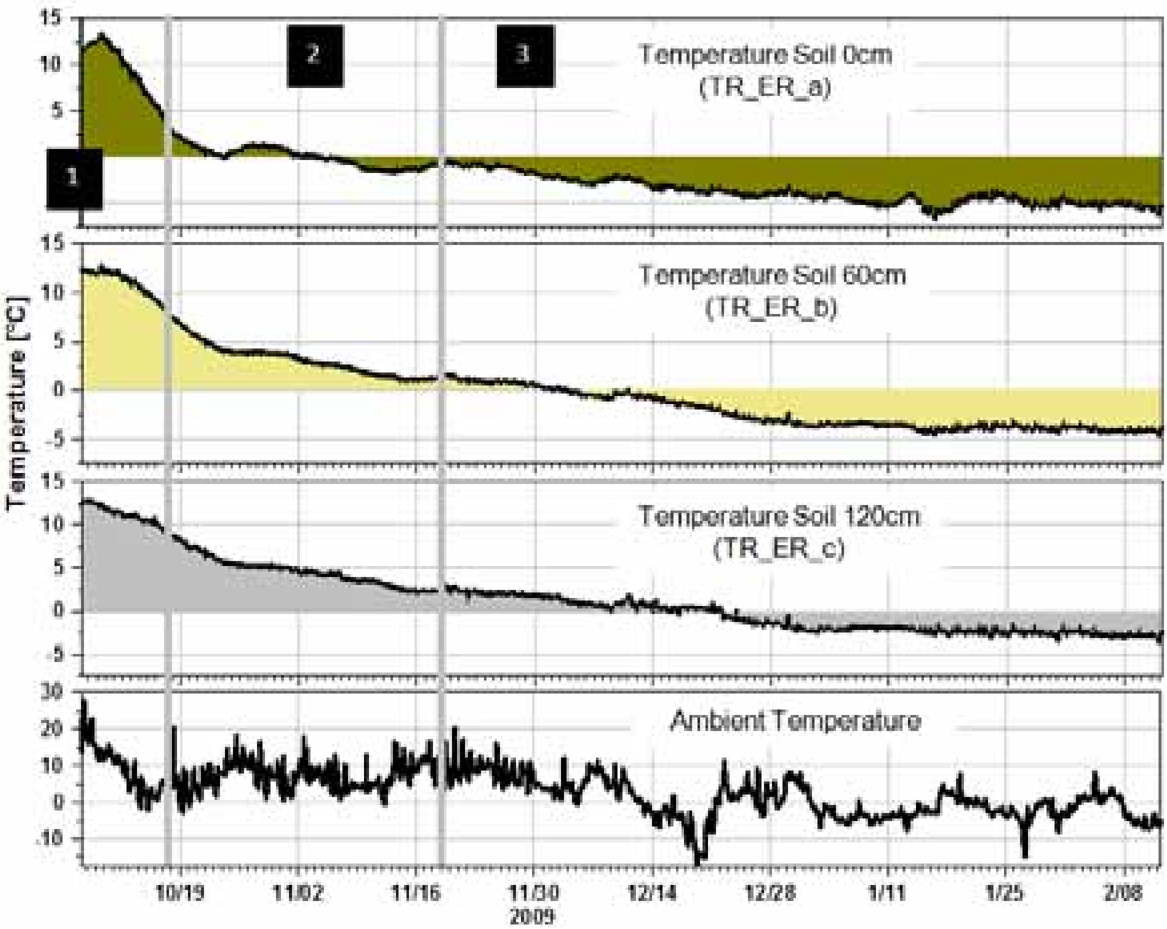

Figure 5: Soil temperature at different distances to the latent heat storage tank

At a distance of 60 cm and 120 cm, the water/ice latent heat storage tank has a lower influence on the surrounding soil. At a distance of 60 cm, the soil reached the freezing point in the beginning of December with a notable delay compared to the water/ice latent heat storage tank. Afterwards, the temperature remained constant at approximately -4°C. At a distance of 120 cm, the freezing point was reached in the mid of December and remained constant at approximately -3°C, which was close to the ambient temperature at that time.

4. Challenges in practical operation under field-testing conditions

In the course of the continuous analysis of the operational data, also the system functions under different operating conditions were evaluated. As one result, for example a problem with the hydraulic system was identified, when a simultaneous charging of the buffer storage tank and the latent heat storage tank with solar-thermal energy appeared in summer 2009 (figure 6). As this behaviour was not considered in the control strategy, it had to be evaluated as a system malfunction, which finally could be identified as the probable cause for a damage of the collectors' heat exchanger. The reason for the simultaneous charging was traced back to a defective, meaning not completely closing, 3-way valve which was replaced subsequently.

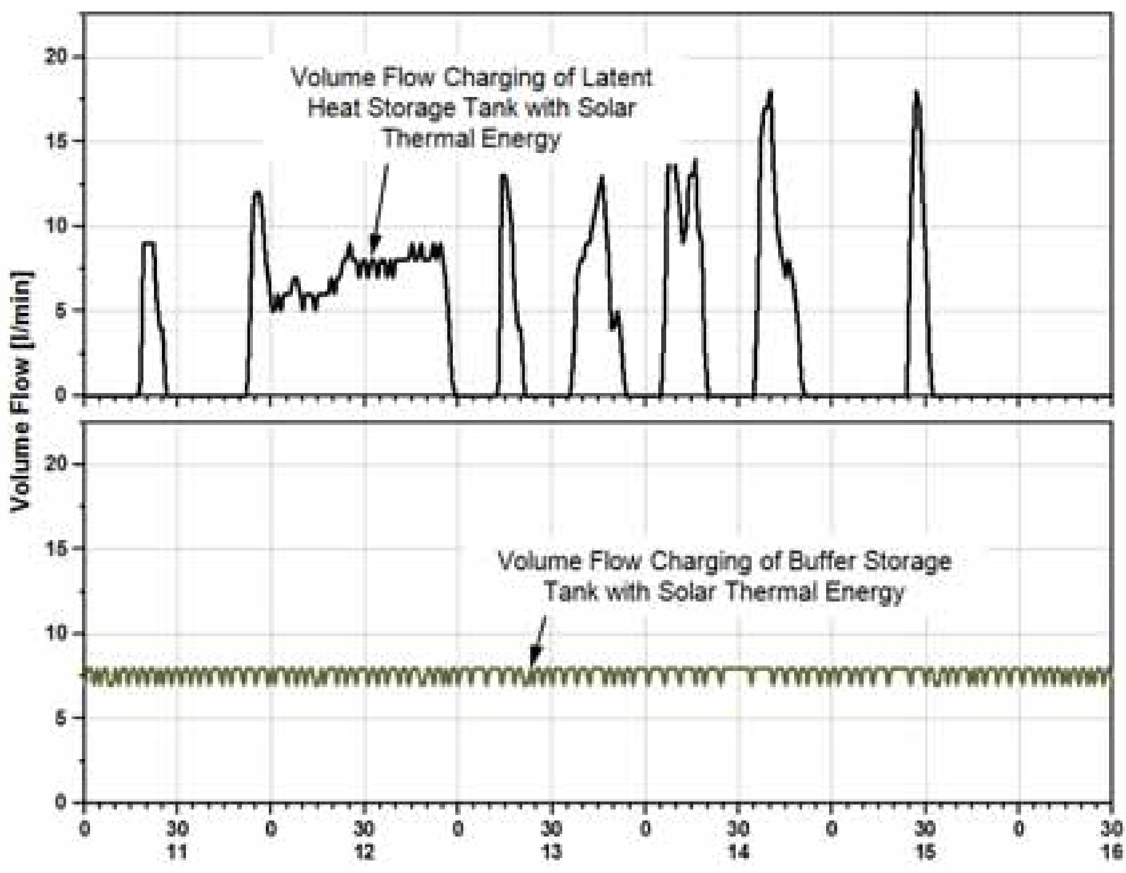

Figure 6: Charging of the latent heat storage tank and buffer storage tank with solar-thermal energy

This example shows, that even failure or malfunction of standard components can cause unintended system behaviour and damage components in these complex heating systems. Complete malfunction of the overall system concerning energy-efficient operation has to be considered as one consequence. Hence, the implementation of control units monitoring the basic functions of the system including adequate self-control strategies is most desirable.

In order to prevent condensation or even frost within the building, it has to be pointed out, that a high quality (cold) insulation for the whole low-temperature side of the system including hydraulic components is of major importance.

5. Conclusion

The presented field-testing analysis of the solar/heat pump heating system achieved revealing results with regard to practical operation. These implementation experiences provided the possibility to identify tangible potentials for improvement in system hydraulic and supervisory control, which in part have already been realised in the system. Aiming at further optimisation of the system, the scientific monitoring in context of the project with the industrial partner *Ratiotherm Heizung + Solartechnik* is continued. Certainly, an energetic evaluation of the system should be carried out on an annual basis.

The experiences in practical operation showed, that on the one hand the implementation of this complex system as well as the operational monitoring is challenging, but on the other hand also the quality of (standard) components should not be neglected. Both issues indicate the need for the development of 'plug-and-play' or 'ready-to-install' system kit solutions, at least to avoid errors in dimensioning and assembling. To ensure energy efficient operation of such solutions, a control unit which continuously monitors the basic functions of the system including adequate system self-control strategies should be aspired.

Moreover, for the development of solar/heat pump heating systems and adequate components, experiences confirm that intensive field tests are mandatory. Typically, solar/heat pump heating systems are complex in hydraulics and control technology, which means that besides simulation also practical experiences and identification of potentials for improvement are of essential importance. In conclusion, these steps are meant to optimise and ensure reliability of series products under diverse operating conditions.

In this context, laboratory tests compared to field tests seem to be of limited significance. In particular, if only single components or subsystems are tested. Especially solar/heat pump heating systems with ground-coupled stores are to a high extent subject to site-specific conditions, which cannot be tested in laboratory without unreasonably high effort and costs.

Special operating conditions for single systems or components, such as the solar-thermal collector, which can differ significantly from standard collectors, have to be taken into account. At this point, a considerable amount of effort in research and development at all levels of the product development process has to be contributed in theory as well as in practice before standardised test methods can be established.

References

[1] Trinkl, C.; Zörner, W.; Hanby, V. (2004) A Review on Solar-Assisted Heat Pump Systems for Domestic Heating. *5th ISES Europe Solar Conference (EuroSun2004)*, Freiburg (Germany)

[2] Müller, H.; Trinkl, C.; Zörner, W. (2009) Domestic Solar/Heat Pump Heating Systems: Market Overview, Systems and Component Technologies. *4th European Solar Thermal Energy Conference (estec2009)*, Munich (Germany)

[3] Leibfried, U.; Günzl, A.; Sitzmann, B. (2008) SOLAERA: Solar-Wärmepumpensystem im Feldtest. *18. Symposium Thermische Solarenergie*, Bad Staffelstein (Germany)

[4] Fellner, A.; Kruck, A.; Trinkl, C.; Weidinger, A; Zörner, W. (2003) New Technology for Solar Heating: Concept and Application of a Fuel-Free, Solar-Based Heating System for Family Houses. *European Solar Thermal Energy Conference 2003 (estec2003)*, Freiburg (Germany)

[5] Trinkl, C.; Zörner, W.; Hanby, V. (2005) Solar-Assisted Domestic Heating with Heat Pump and Latent Heat Storage. *2nd European Solar Thermal Energy Conference 2005 (estec2005)*, Freiburg (Germany)

[6] Trinkl, C.; Zörner, W.; Hanby, V. (2008) A Domestic Solar/Heat Pump Heating System incorporating Latent and Stratified Thermal Storage. *ASME 2nd International Conference on Energy Sustainability*, Jacksonville (USA)

[7] Trinkl, C.; Zörner, W.; Hanby, V. (2009) Simulation study on a Domestic Solar/Heat Pump Heating System incorporating Latent and Stratified Thermal Storage. *ASME Journal of Solar Energy Engineering*, 131 (4), 041008

[8] Trinkl, C.; Zörner, W.; Hanby, V. (2007) Solarbasiertes Wärmepumpenheizungssystem: Systemuntersuchung und Latentwärmespeicherentwicklung. *17. Symposium Thermische Solarenergie*, Bad Staffelstein (Germany)

[9] Kroker, J.; Faber, C.; Trinkl, C.; Zörner, W. (2008) Solarbasiertes Wärmepumpenheizungssystem mit Latentwärmespeicher: Systemoptimierung und Feldtestmessung. *18. Symposium Thermische Solarenergie*, Bad Staffelstein (Germany)

[10] Kroker, J.; Lanz, M; Faber, C.; Sonnleitner, M.; Trinkl, C.; Zörner, W. (2009) Solar-Wärmepumpensystem mit Latentwärmespeicher: Parameterstudie und Feldtestmessung. *19. Symposium Thermische Solarenergie*, Bad Staffelstein (Germany)