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Thermal Storage Tanks in High Efficiency Heat Pump Systems – Optimized Installation and Operation Parameters

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Abstract

Heat pumps have a significant and increasing share in the European heating market. In most applications heat pumps are operated with a storage tank, either for domestic hot water or for the space heating circuit. The design of the storage and its connection to the heat pump has a significant influence on the performance of the heat pump and the whole system.
Within a comprehensive investigation, system simulations in TRNSYS are used to identify the optimum design of two typical systems with a heat pump connected to a buffer storage including total storage volume, number and size of heated zones, sensor and in- and outlet positions.
As result, a sharp decrease in the energy demand can be reached if the storage is equipped with two heat zones instead of one. This can be explained by the decreased set temperature in the additional heat zone for space heating leading to a higher performance of the heat pump. Other measures with a positive effect on the energy demand are a large space heating volume, the number and place of sensors, low set temperatures and the sensor position in the upper part of the heating zone.
The investigation gives important recommendations how to connect a heat pump with a storage tank and may be considered as design rules for all heating systems consisting of heat pump and different types of storage tanks.

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*Keywords:*solar active house; heat pump; storage tank, TRNSYS; system simulation

1. Introduction

Heat pumps have a significant and increasing share in the European heating market, e.g. in Germany 10% of the heat generators in buildings installed in 2013 have been heat pumps [1]. In most applications heat pumps are operated with a storage tank, either for domestic hot water or for the space heating circuit. The design of the storage

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and its connection to the heat pump has a significant influence on the performance of the heat pump and the whole system [2].

Within a comprehensive investigation, system simulations in TRNSYS are used to identify the optimum design of a solar thermal system with a heat pump connected to a buffer stor-age. This includes the total storage tank volume, the number and sizes of heated zones, and the sensor as well as the in- and outlet positions. The system represents a new concept of a solar active house with a solar thermal fraction of more than 50 % with significant lower costs than usual solar houses. The scheme in Figure 1 gives an overview of the system con-cept with its main components.

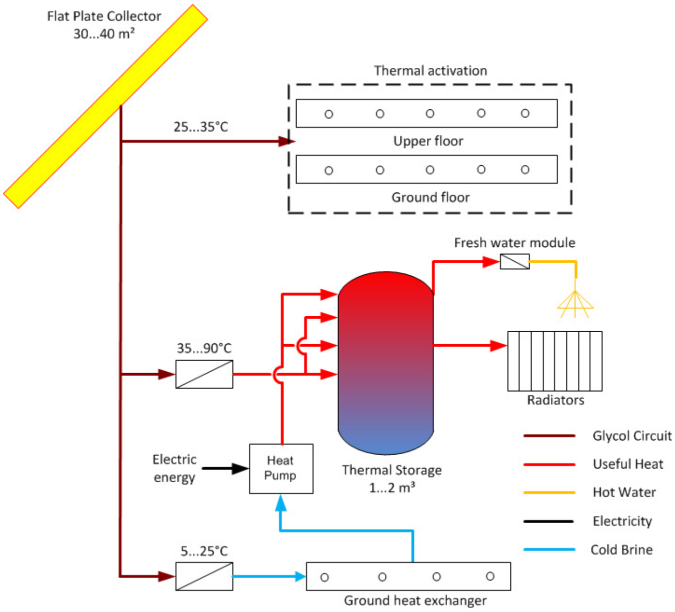

Figure 1: Scheme of the solar thermal heating system for the investigation (the lines indicate energy flows)

The collector field delivers heat to three different heat sinks – a buffer storage, a directly heated thermally activated concrete floor (TABS = thermally activated building systems) and a ground heat ex¬changer, which serves as the heat source for the heat pump repre-senting the back-up heater. Within the present investigation the system serves as a back-ground for the analysis of the connection of heat pump and storage tank. A detailed system description and analysis with a focus on the solar thermal performance is published in [3].

2. Methodology

The system presented in **Fehler! Verweisquelle konnte nicht gefunden werden.** is simulated in TRNSYS 17 [4] under the boundary conditions shown in Table 1.

Table 1: Boundary conditions forthesimulations in TRNSYS

	Data	TRNSYS Type/Model
Location	Zurich, Switzerland	Weather data from Meteonorm[5]
Building		
Heated area	184 m²	Type 56 [4]
Heat demand	11800 kWh/a (constant infiltration rate 0.4 h^{-1}/20 °C room temperature)	
Space heating		
Type	Radiators	Type 362[6]
Design temperatures (Flow/return)	55 °C / 45 °C at -14 °C ambient temperature 35 °C / 30 °C at 20 °C ambient temperature	
Domestic hot water demand	2200 kWh/a	Based on IEA Task 44[7]
Collector	32 m² selective flat plate collector/tilted 45°, south	Type 832 [8]
Storage tank		
Dimensions	Volume 1 m³, height 2 m, diameter 0.8 m	Type 340[9]
Heat loss rate	Insulation 0.1 m with 0.037 W/mK, overall heat loss 4.1 W/k	
Heat pump		
Working point B0/W35 (DIN EN 255)	Heating power 8.1 kW (condenser output),COP 4.8	Type 401[10] and Type 292 for flow rate adaption[11]
Volume flow rates	Evaporator 1.9 m³/h, condenser 0.7 m³/h	
Dynamics	Heat up constant 30 s, cool down constant 5 min, minimum turn-off time 10 min	
Heating rod	Power 7 kW	
Heat source	Borehole with 70 m depth	Type 557[12]

The buffer storage supplies the fresh water station (FWS) and the space heating (SH) loop and is charged by the heat pump and 32 m² of solar thermal collectors. The connection of buffer storage and heat pump can be realized that the heat pump may charge only one storage zone for SH and DHW. In case of two heated zones, the upper zone supplies the heat for the DHW preparation while the lower zone is used for SH. Figure shows all connections to and from the buffer storage in the case of two heated zones in the buffer storage. In addition, the volume of the sections and the relative heights of the storage connections set within the base case are indicated.

The specific in-/outlet positions of the storage tank depend on the charging variant (one or two heated zones) and the volume of each zone. The following sections of the storage tank can be defined.

- The dead volume is situated above the upper heated zone between outlet to the FWS and inlet of the heat pump.
- The DHW volume is charged directly by the heat pump to its set temperature (base setting: 50 °C). Charging the DHW zone has a higher priority than the SH zone.
- The separation volume separates both heated zones.
- The SH volume is used for space heating and is charged with second priority. The set temperature may constant or variable following the desired flow temperature according to heating curve and ambient temperature (setting in base case).
- The solar volume is only charged by the solar thermal collectors.

The whole system performance is analyzed with simulations. Several parameters characterizing the heat pump storage connection are varied – in most cases only one parameter is varied while the others are kept constant.

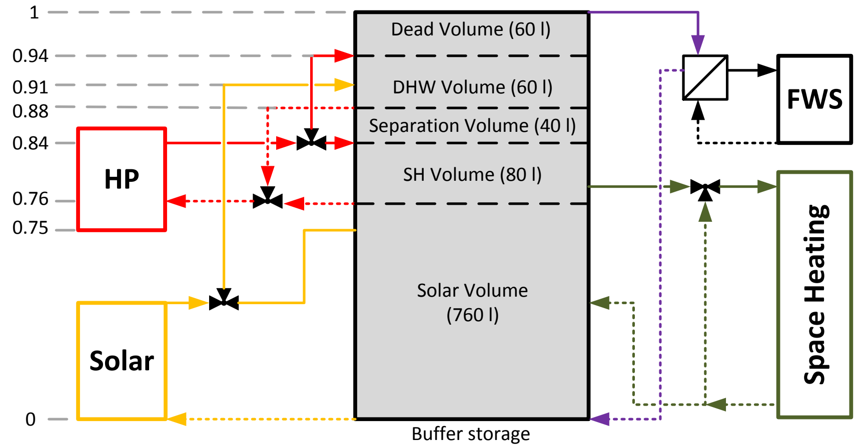

Figure 2: Scheme of buffer storage with two heated zones and its connections to heat pump, solar thermal collectors and heat sinks, sections of the storage with the values of the base case, on the right: relative heights of storage connections (0 to 1) for the base case

3. Results

This section presents the results of the simulations. The main evaluation value is the total annual electricity amount consumed by the whole system including heat pump, heating rod, all circulation pumps and controllers. The heat pump performance is evaluated with its seasonal performance factor (SPF), which is the ratio of the heat pump output to the electricity consumption in the period of one year.

3.1. Heated zones

The scheme inFigure shows two heated zones within the buffer storage. The hydraulic connection between heat pump and buffer storage is less complex if only one heated zone is used (see Section 2). The disadvantage of this concept is that the whole auxiliary zone has to be heated to one set temperature supplying both DHW and SH. Figure gives the main results of both variants, which were simulated with the same overall auxiliary volume of 240 l (60 l dead and 180 l directly heated volume in the case of one heated zone, volumes with two heated zones according to Figure).

The heat pump delivers more than 8 MWh to the auxiliary volume of the buffer storage, in the case of two heated zone only 5 % of the heat amount is delivered to the upper zone with a temperature of 57.0 °C. Due to the significant lower charging temperature to the space heating section of 43.7 °C, the average condenser outlet temperature is 44.4 °C which is 6 K below the value with one heated zone. The lower temperature level at the condenser increases the seasonal performance factor of the heat pump by 0.33 leading to a reduced electricity amount consumed in the heat pump. The system performance increase by 0.32 in SPF and the whole system consumes almost 250 kWh less electricity (10 %).

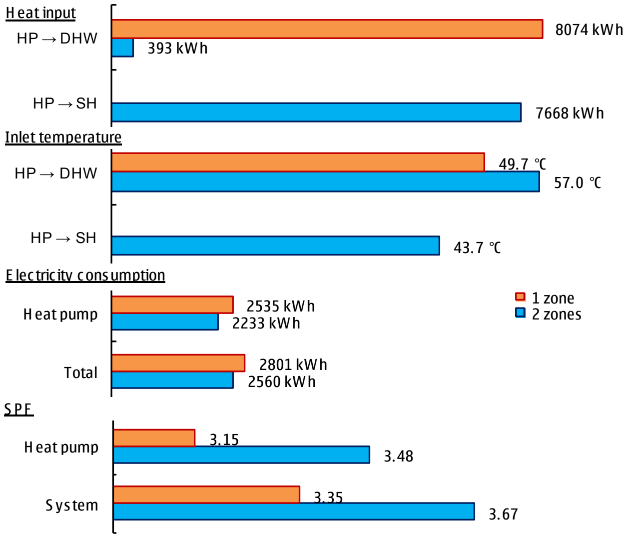

Figure 3: Annual heat pump and system performance figures with one or two heated zones

For a more detailed analysis, the diagram of Figure shows the heat amount delivered from the heat pump to the storage and from the storage to the heat sinks partitioned by the respective in-/outlet temperature (temperature classes of 2 K). It has to be noted that the heat pump covers less than 50 % of the heat demand of the fresh water station while the rest is provided from the solar thermal collectors. This heat amount is only partly shown in the diagram since the collector input and thus the storage outlet reaches often temperature above 64 °C, especially during summer season (see e.g. [3]).

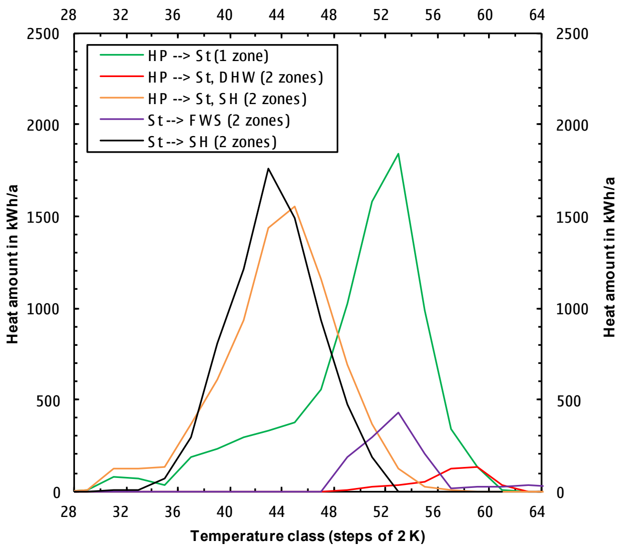

Figure 4: Energy-temperature diagram: heat pump to storage in case of one heated zone (HP → St) or two heated zone (HP →St,DHW / HP →St,SH) as well as storage to space heating (St → SH) and storage to fresh water station (St → FWS) in the case of two heated zones – both show only small differences if one heated zone is used

The diagram reveals the advantages if the heat pump charges two heated zones:

- For one heated zone the diagram shows a significant discrepancy between the temperatures delivered to the storage tank by the heat pump (between 30 °C and 60 °C, in average 49.7 °C) and consumed by the fresh water station and in specific by the space heating (36 °C to 52 °C). While the fresh water station is able to utilize higher storage temperatures, a valve in the space heating loop mixes them to a lower level according to the heating curve.
- In the case of two heated zones the heat pump charges mainly the space heating zone on a significant lower temperature level than the DHW zone. Compared to one heated zone the heat input corresponds considerably better to the heat amount consumed by the space heating loop resulting in lower condenser temperatures and thus a higher heat pump performance.

3.2. Auxiliary heated volumes and their arrangement

The total volume heated by the heat pump may be modified by its size and the subdivision in the four part volumes according to Figure . Figure shows the electricity consumptionof the whole system for different volume variants. The results are sorted by the volume of the space heating and the sum of the other three volumes.

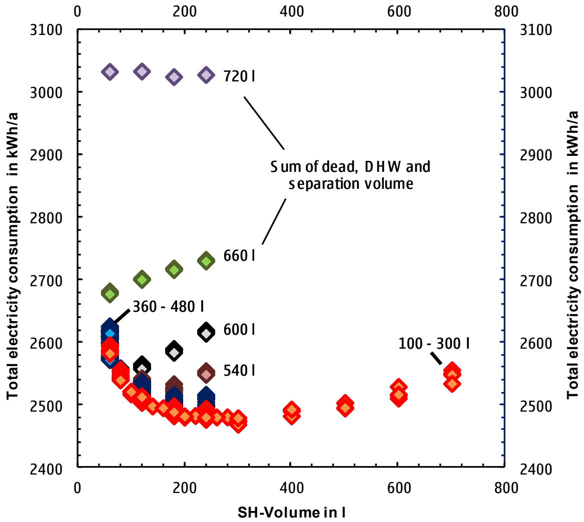

Figure 5: Systems total electricity consumption depending on the volume for space heating and the sum of the other three sections

The figure identifies the variants with the lowest electricity consumption:

- Increasing the sum of the three upper volumes increases the total electricity consumption, thus the highest values occur at 720 l. Below 720 l the consumption depends additionally on the SH volume. Between 540 l and 660 l a small SH volume leads to a smaller consumption on a comparatively high level. Below 540 l the lowest electricity consumption is reached at SH volumes between 200 l and 300 l.
- Apart from its total sum a more detailed analysis shows that the subdivision of the three upper volumes does not have a significant impact on the result. Most importantly, both the dead and the separation section, although necessary, shall have a small volume while the DHW volume should be around 100 l at the given DHW load.

3.3. Set temperature and sensor position

Besides the volume, sensor positions and set temperatures have an impact on the heat amount stored in the auxiliary volumes. In the case of two heated zones, the DHW zone should be controlled by a constant set temperature (50 °C in the base case), the set temperature in the SH zone may be constant or variable following the heating curve, optionally increased/decreased by an additional term. Figure shows the overall electricity consumption for different set temperatures of DHW and SH zone – all variants shown fulfill the comfort conditions.

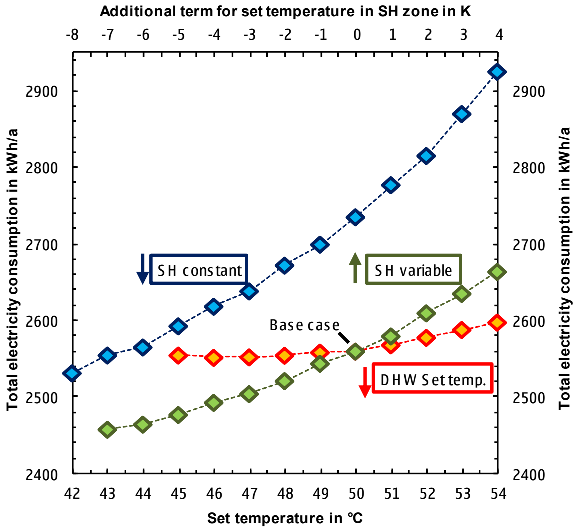

Figure 6: Systems total electricity consumption in case of two heated zones depending on the set temperatures, different variants for the SH set temperature: constant or variable temperature depending on the heating curve under consideration of an additional term, circle marks result with base case conditions

The diagram shows the dependence between electricity consumption and set temperatures:

- Since the heat pump rarely charges the DHW zone, its set temperature has a small impact. The electricity amount decreases by only 5 kWh/a if the set temperature is reduced from 50 °C to 45 °C.
- The set temperature in the SH zone has a significantly higher effect on the heat pump and system performance. The electricity consumption reaches values from 2460 kWh/a to 2950 kWh/a.
- A variable set temperature in the SH zone gives better results than a constant value since it leads to lower condenser temperature in the case of higher ambient temperatures. Compared to the base case the set temperature may be decreased by 7 K indicating – for the weather data used – that either the space heating elements are oversized or the flow temperature is unnecessarily high.

Figure shows the electricity consumption and the cycle frequency of the heat pump depending on the sensor positions in the two heated zones.

The position of the DHW sensor has almost no effect on the cycling frequency and a comparable small effect on the electricity consumption with lower values at a high position. The same trend can be seen at the SH sensor – the electricity consumption and the cycling rate decrease at higher positions. The smallest electricity amount is consumed at the highest possible positions (comfort conditions fulfilled) of both sensors.

Two sensors in each heated zone enable the so-called boiler charging: The storage charging begins, if the temperature at the upper sensor cools down to the turn-on temperature, and stops, if the turn-off temperature is reached at the lower sensor. By varying the set temperatures and the positions of both sensors in the simulations, the optimum configurations were found. Compared to the best variants with one sensor the heat pump works almost on the same temperature level. Thus, the higher effort with two sensors does not lead to a better system performance.

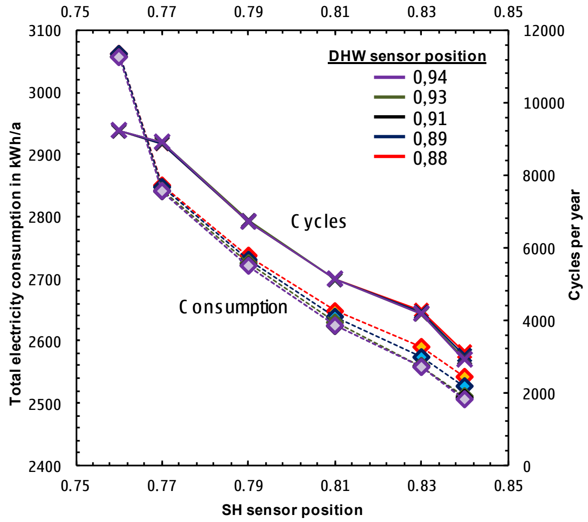

Figure 7: Systems total electricity consumption and cycles per year depending on DHW and SH sensor position in the base case acc. to Figure 2

3.4. Heat pump flow rates

The volume flow rates are varied on the condenser and the evaporator side based on the nominal values according to Table 1. Apart from the heat pump itself, the flow rates also influence the electricity consumption of the circulation pump especially on the evaporator side due to the high pressure losses in the ground source loop. The simulations require a heat pump model adaptation to variable flow rates (see Table 1). Figure shows the electricity consumption including all circulation pumps for all variants as well as the cycling rate and the temperatures of the heat pump for one evaporator flow rate at different condenser flow rates.

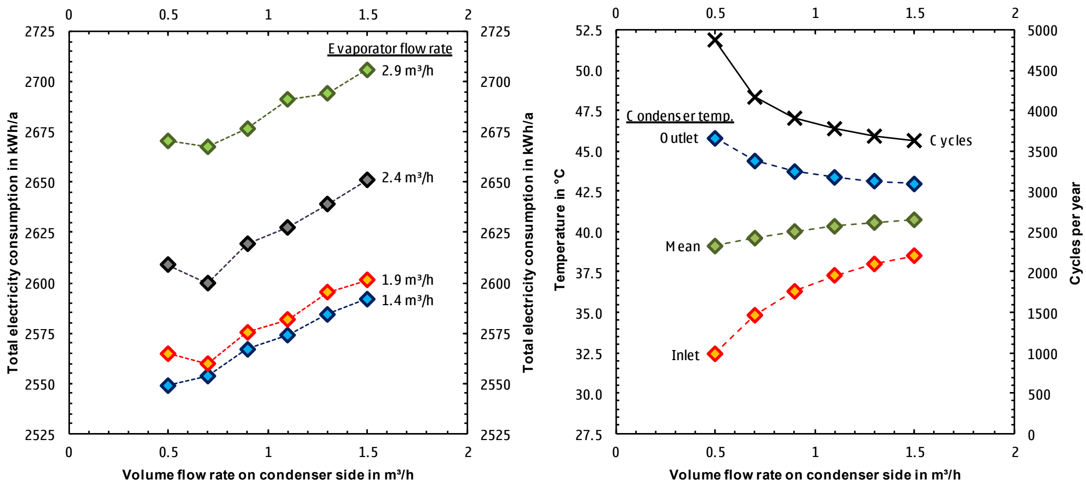

Figure 8: Left: Systems total electricity consumption depending on condenser and evaporator flow rates, right: Energy weighted mean condenser temperatures and cycles per year for different condenser flow rates at an evaporator flow rate of 1.9 m³/h

Due to the pressure drop, the source pump requires at higher evaporator flow rate significantly higher electricity consumption. A higher condenser flow rate also increases the electricity consumption, although the pressure drop remains almost unchanged. A higher flow rate increases the mixing within the simulated storage tank, in which turbulence effects at the in- and outlet are not even regarded. This leads to higher condenser inlet and mean temperatures, thus resulting in higher electricity consumption. This effect exceeds the positive impact of a decreased cycling rate with lower start-/stop heat losses at high condenser flow rates.

4. Discussion and conclusion

The connection between heat pump and buffer storage was investigated for one exemplarily solar thermal system revealing the following results:

- Number of zones: A two zone operation allows using different set temperatures for space heating and DHW preparation. This leads to lower condenser temperatures and thus a better heat pump performance.
- Volumes: The optimum variants have a DHW volume of 100 l and a SH volume between 200 and 300 l. Dead and separation zone are necessary but may be reduced to a small volume of e.g. 40 l each.
- Set temperature: In case of two heated zones, the set temperature of the DHW zone has only a small impact on the system performance, while the set temperature in the SH zone should be variable according to the heating curve. The design of the space heating components and the specification of the heating curve play an important role to avoid unnecessary high condenser temperatures.
- Sensor position: The sensor position defines the volume which is kept on the set temperature. A high sensor position reduces this volume and thus the electricity consumption and the heat pump cycles. A lower sensor position allows a lower set temperature without reducing the comfort. The best combinations of sensor position and set temperatures between 40 °C and 50 °C lead to almost identical total electricity consumption values. The use of two sensors in each heated zone shows no advantage.
- Flow rate of heat pump: Both flow rates should be minimized with regard to the characteristics of the ground heat exchanger in case of the evaporator and to the rise of the inlet temperature in case of the condenser side.
- Overall: The total electricity consumption may be reduced by 15 % with an optimal heat pump storage connection compared to the base case with one heated zone.

This study reveals from simulations in one defined heating system important facts regarding the connection of heat pump and storage tank. For a more general view, the study has to be extended to different systems and boundary conditions. In addition, test rig experiments should be carried out to verify and extend the outcomes.

5. Acknowledgement

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6. References

[1] Bundesindustrieverband Deutschland Haus-, Energie- und Umwelttechnik e.V. (BDH), Bilanz Heizungsindustrie 2013
[2] Haller, M, et al. Hydraulic integration and control of heat pump and combi-storage: Same components, big differences, Energy Procedia 48, pp. 571-580, 2014
[3] Glembin J, et al. Solar active building with directly heated concrete floor slabs, Energy Procedia 48, pp. 561-570, 2014.
[4] Klein SA, Beckmann WA, Mitchell JW, Duffie JA, Freeman TA. TRNSYS 17, A Transient System Simulation Program, Solar Energy Laboratory University of Wisconsin, Madison, 2009.
[5] Remund J, Kunz S. Meteonorm Data (Worldwide), METEOTEST, Bern, Switzerland, 2003
[6] Holst S. Type 362 Dynamic radiator model with pipes (Type 162), Bayerisches Zentrum für angewandte Energieforschung e.V., München, Germany, 2010.
[7] Dott R, Afjei T, Dalibard A, Carbonell D, et al. Models of Sub-Components and Validation for the IEA SHC Task 44 / HPP Annex 38 Part C: Heat Pump Models, A technical report of subtask C Deliverable C2.1 Part C, International Energy Agency, 2012.
[8] Haller M, Perers B. Type 832, Dynamic Collector Model, Institut für Solartechnik, Hochschule für Technik Rapperswil, Zurich, Switzerland, 2012.
[9] Drück H. Type 340, MULTIPORT Store - Model for TRNSYS, Institut für Thermodynamik und Wärmetechnik (ITW) Universität Stuttgart, Stuttgart, Germany, 2006.
[10] Afjei T, Wetter M. Type 401,Compressor heat pump including frost and cycle losses, Zentralschweizerisches Technikum Luzern, Ingenieur-schule HTL, Zurich/Luzern, Switzerland, 1997.
[11] Institut für Solarenergieforschung Hameln ISFH. TRNSYS Type 292: Component for heat pump to correct for different flow conditions in condenser or evaporator, 2013
[12] TESS COMPONENT LIBRARIES General Descriptions, Tess Thermal Energy System Specialists, Madison, Wisconsin, USA, 2011.