Direct solar thermal systems with thermosiphon frost protection and innovative control strategies using a Thermo-Differential Bypass Valve

Summary

This research involves a direct solar (combi-)system for use in cool climates, based on vacuum-tube collectors, that uses night-circulation for frost protection, which doesn't rely on pumped circulation, but also provides frost protection through thermosiphon circulation as a back-up in case of power/control failures. Furthermore, this direct solar system does not use a collector sensor or storage tank sensor, but instead has both the temperature sensors integrated into the pumping station. These features are achieved by using a Thermo-Differential Bypass Valve, which is installed on the storage tank at the solar inlet, and which only opens when the solar supply temperature is higher than the storage tank temperature and bypasses the storage tank when the supply temperature is lower than the storage tank temperature. The solar circuit can thus be free of check valves, so it is free to thermosiphon when the pump is off, and the collector circuit can be regularly circulated to measure the collector temperature at the pumping station, without sacrificing system efficiency.

1. Introduction

The use of the Thermo-Differential Valve (TDV) has been previously reported for the application of promoting stratification in solar combi systems[1], where the TDV is used to direct the solar supply flow to the appropriate height in a (combi-)storage tank for solar systems. In this work a very similar valve is used, except that the valve is used to bypass the storage tank completely, and the valve for this purpose is named a Thermo-Differential Bypass Valve (TDBV). The use of the TDBV isolates the solar circuit from the storage tank when the temperature of the solar supply flow is lower than the temperature inside the storage tank (at the height where the TDBV is installed) and allows flow to take place in the solar circuit without potential heat loss from the storage tank. This feature is used to position all the sensors for the controller inside the solar pumping station, and use circulation to detect the temperature of the collector and the storage tank temperature. The periodic circulation takes place 24 hours per day, also at night, and when the temperature in the solar circuit drops below a lower limit, a thermostatic frost protection valve opens, allowing a small amount of heat from the tank to flow into the solar circuit, just enough to maintain it at the preset minimum temperature. When there is a power failure, and the periodic pumped circulation no longer takes place, thermosiphon flow starts circulating when the collector is cold and at risk of freezing (with the collector positioned at the highest point in the solar circuit), and in this case also the thermostatic frost protection valve adds heat to the solar circuit to maintain the preset minimum temperature. See also Figure 1 for schematics of the direct solar system.

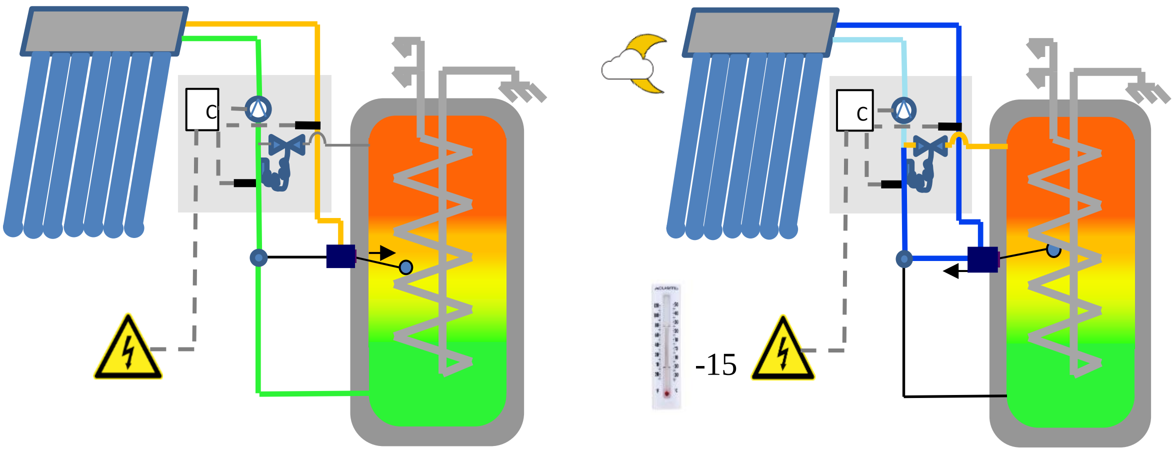

Fig. 1: Direct solar system with TDBV in normal operation (left) with the TDBV in open position and the thermostat valve closed, and during frost protection (right) with the TDBV in bypass position and the thermostat valve open

2. Experimental

To test and further develop the direct solar system, a prototype was built at our location in Veldhoven, the Netherlands. Some basic details about this prototype are given in table 1:

Collector array:	2 x TWL HLK-30, vacuum tube (Sydney), heat pipe
Orientation:	South, 45° inclination
Collector array area:	Gross: 9.98 m2, Aperture: 5.56 m2
Collector parameters:	$\eta_0 = 0.761$, $a_1 = 2.299$, $a_2 = 0.010$
Storage tank:	900 litre steel buffer-tank (no heat exchangers in tank)
Solar tubing:	2 x 15 meter DN16 ribbed stainless steel

Tab. 1: Selected details of direct solar system prototype

To study the thermosiphon behavior in different and realistic conditions, negative loops were introduced into the tubing (see also Figure 2). The first negative loop is on the flat roof, where the tubing runs along the roof floor, before rising 25 cm into the roof passage (also, the tubing on the roof was installed symmetrically – 2 x 2.5 meter of outside tubing – to create a worst-case-scenario for thermosiphon flow starting up), the second negative loop is indoors, and is variable, dipping up to 1 meter.

Fig. 2: Images of direct solar system with TDBV; collector array (left), adjustable negative loop (middle) and the storage tank (right) with TDBV installed at 0.5 relative height, and thermostat valve at 0.8 relative height

3. Results

Results have shown that optimal performance in sampling mode is achieved by circulating the solar circuit once around during the periodic sampling. By circulating the fluid once around, the fluid is returned to the same position in the solar circuit (when the TDBV does not open), so the collector fluid returns to the collector when it isn't hot enough for the TDBV to open. This prevents the tubing from becoming unnecessarily warm, and particularly in low intensity (e.g. highly diffuse irradiation) this results in much improved performance. Custom control software has been developed to automatically determine and set the optimal circulating time, corresponding to circulating the fluid once around. The time between periodic sampling was varied, and a time of 10 minutes was found to yield good results. The controls switch to continuous flow when the TDBV is still open at the end of the periodic circulation. The periodic circulation continues at night, and provides frost protection, with the thermostat valve (set to frost protection, nominally 6°C according to datasheet) opening at cold nights, resulting in a minimum collector temperature of 6°C (at ambient temperature -10°C). The electricity supply is switched off every night for around 3 hours, to observe the thermosiphon behavior. It is observed that thermosiphon flow can start up in either the forward or reverse direction, and the system was modified so that the thermostat valve can observe the coldest temperature in both thermosiphon flow directions. The thermosiphon flow was tested in various conditions, with a large negative siphon, and low tank/ambient temperatures. It was found that the critical factor is the starting up of the thermosiphon flow after the electricity supply is cut, however in even very adverse conditions positive results were achieved

References:

1) Van Ruth, N.J.L., 2016. New Type of Valve for Solar Thermal Storage Tank Stratification. Energy Procedia 91:246-249