DRAINBACK SYSTEMS AS AN EFFICIENT AND SAFE SOLUTION FOR SOLAR DHW INSTALLATIONS: PRACTICAL EXPERIENCE

Daniel Mugnier[1], Louis Casals[2], Romain Siré[2] , Amandine Le Denn[2]

[1] TECSOL, Perpignan (France)

[2] TECSOL, Perpignan (France)

1. Introduction

In order to insure the durability of solar thermal installations, a self-drain solution called “drainback system” was developed in the 1980’s. Basically, this solution permits to avoid any risks of frost and overheating in the solar thermal collector fields. This safety system works on every solar installation, but it’s more likely to be installed on medium and large scale solar thermal systems which are especially affected during overheating periods. Even if this kind of system is a very promising one, the technology is still paradoxically not widespread because it’s not well known and implemented.

2. System description and principles

2.1. Main differences between a pressurised system and the innovative drainback concept

When a drainback system is adopted, several changes must be performed in comparison to the conventional pressurized systems. The main differences between a traditional large Solar Domestic Hot Water system (cf. Figure 1.) developed by the French Engineering company TECSOL (www.tecsol.fr) and a drainback one is the following:

- replacement of the overall safety devices (expansion vessel, safety valve, pressure meter) by a closed and air proof stainless steel tank ;
- withdrawal of air vents, no return valve and of the filling pump

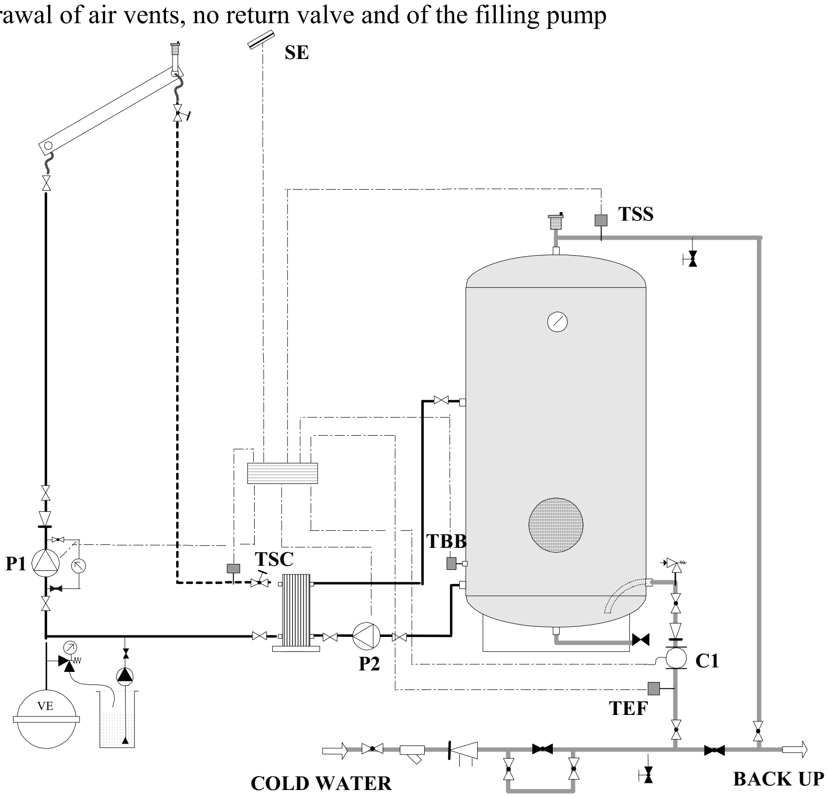


Fig. 1: Traditional pressurized large solar domestic hot water system scheme

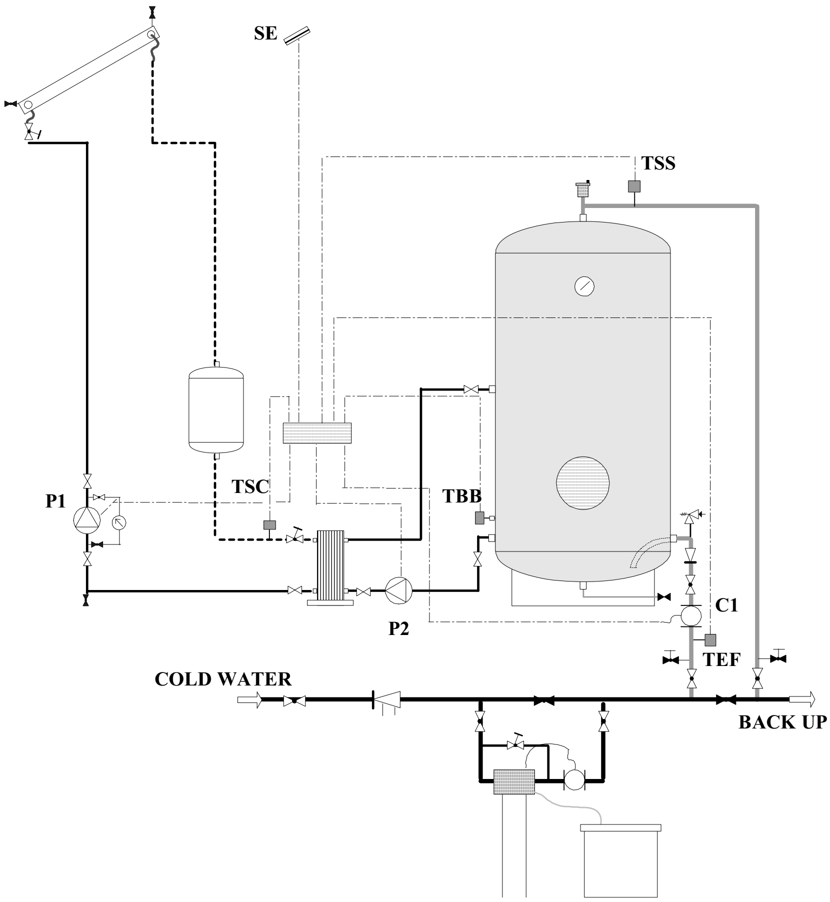


Fig. 2: Drainback large solar domestic hot water system scheme

It is to note that with this new configuration (cf. Figure 2), the control strategy is exactly the same for the two configuration except how to manage the overheating risk because for the drainback configuration, this protection is only achieved by stopping the 2 pumps whereas in a standard system, it is often better to keep running the pumps so as to cool down the circuit during night time. Moreover, in certain pressurized systems, the overheating protection is achieved by stopping pumps et oversizing expansion vessel(s) so as to absorb the fluid expanding because of vaporization into the collectors (vessel volume 3 to 4 times bigger than a normally designed vessel necessary in this case) which constitutes an important risk of accelerated ageing for the heating fluid and the installation.

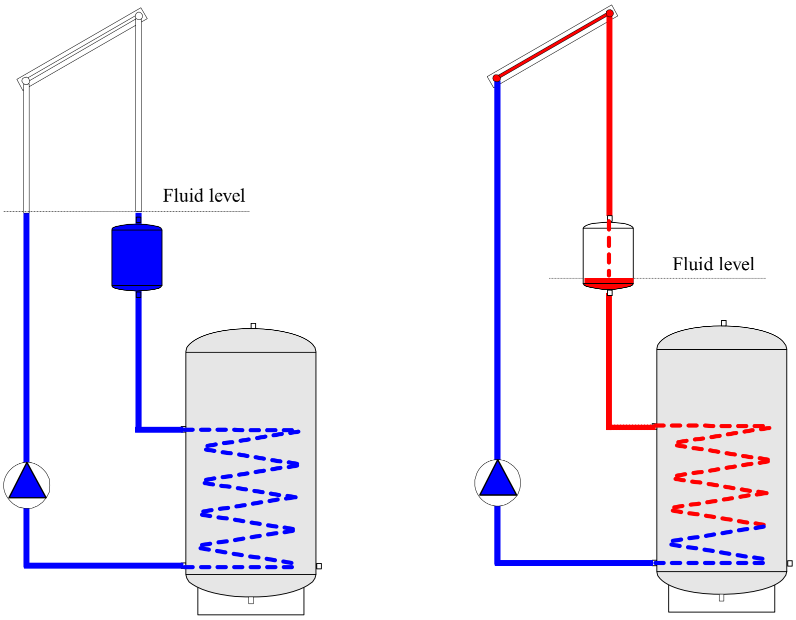
In the design of TECSOL installations, the control rules for drainback are following (see Figure 2 for symbols of components):

- Start up of the primary loop pump P1 when the solar irradiance SE > 150 W/m^2 and stop when SE < 120 W/m^2.
- Start up of the secondary loop pump P2 if P1 is ON and when TSC > of 7°C to TBB and stop when TBB < of 2°C to TSC.
- Stop of the both pumps in protection mode against overheating of the storage when TBB > 85°C and allowance to start up again the pumps when TBB < 60°C.

A drainback system is running without overpressure (atmospheric pressure) but need to be air proof however to avoid any risk of oxygenation. For the fill in process of the installation, a specific procedure developed by TECSOL must be respected to take into consideration that the fluid volume in the return side of the primary loop is far bigger than in the other side (because of the drainback tank). The used fluid can be of course pure water but only if the solar collectors are perfectly drainable when the primary loop pump P1 is stopped (harp mode collectors without diameter reduction when assemblied in batteries) and if there is no risk of freezing in the external piping (sufficient slope, lack of high point in the circuit). In the case these conditions cannot be respected (generally), an anti freezing fluid needs to be used even if the required protection level can be lower (-15°C then 30% instead of -25°C i.e 40% of monopropylen-glycol for France) because of lack of freezing risk in the collectors (empty in freezing period). The anti freezing protection in a traditional pressurized installation must take into account during clear sky nights of the absorber temperature decrease due to radiation to the sky. Then, the absorber temperature can be lower than the ambient temperature of several degrees.

2.2. Working principle of a drainback system

The working conditions of a drainback system are described in the following paragraph (see Figure 3 as well): when the pump P1 is stopped, the fluid level is located in the upper part of the loop or above the drainback tank. The collector field and the piping section corresponding to the fluid maximum expansion capacity are filled in with air. When the P1 pump is started up, its manometric head (HMT) must be able to elevate the fluid level to the upper part of the collector field (static pressure) pushing air into the drain back tank like a piston. As soon as the flow is established, the pump head HMT is compensating the loop pressure losses (dynamic pressure).



Pump stopped **Working pump**

Fig. 3: Schematic working principle of a drainback system

The air volume (not renewed) is allowing to empty the collectors when the P1 pump is OFF and to permit the fluid expansion when heating up.

The repartition of volume in the mix is nearly ¾ of fluid for ¼ of air, then the pressure increase due to fluid dilatation (according to perfect gas equation $P_1V_1 = P_2V_2$) and the air one ($PV = nRT$ with flat plate solar collector in stagnation mode then 200°C maxi nearly) is limited to 100%, then a maximum pressure in the collectors of 1 bar. The air volume trapped in the system is therefore playing a role of very efficient fluid expansion zone (the fluid being itself uncompressible).

2.3. System design and particular features

The design and sizing of the drainback installations (collector area, storage volume, heat exchanger features, piping…) must be identical to the one done for a traditional pressurized system. The same rules used by TECSOL to limit the oversizing risks must be respected (par example: limitation to 85% for solar fraction in the best month for DHW production when running the calculation). The installation features must be as well the same for the materials by respecting for instance the following main rules:

- the solar collectors must be in an upper level than the technical premise
- the collectors and interconnections must permit a complete drainback.
- the external main piping connecting the loop to the solar collectors must be always lower than the lowest part of the solar collectors (cf. Figure 4.)

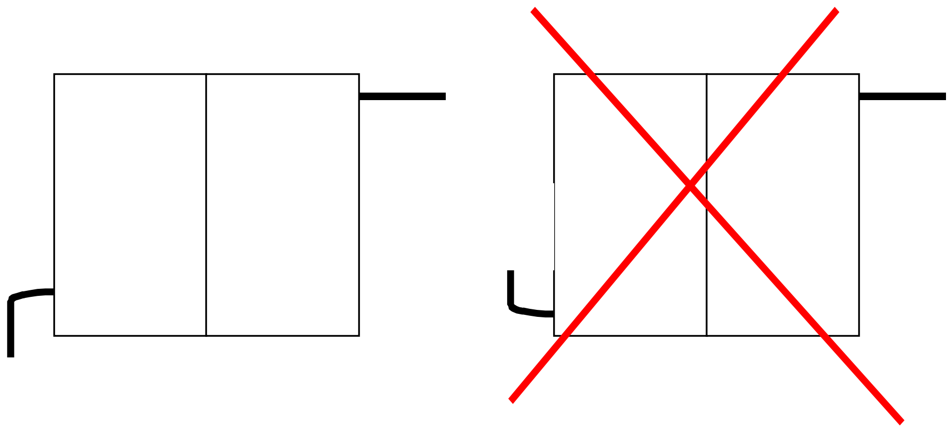


Fig. 4: Correct (left) and incorrect (right) positioning of the collectors in battery for a drainback system

- The drainback tank volume is fixed on the basis of the solar collector total capacity increased by 50%. The useful volume of this tank must be in reality at least corresponding to the solar collector volume plus the volume corresponding to the fluid maximum dilatation variation. For safety reasons, the drainback tank is built in stainless steel (304L) but it can be in black steel if installed in the technical room.
- The tank is installed on the top of the primary pump P1 and below the solar collectors so as to respect the following rules:
  - The height difference between the lowest part of the tank and the pump must be at least equal to the net positive suction head (NPSH) of the pump,
  - The height difference between the highest part of the system (top of solar collectors) and the lowest part of the tank must be less than the pump head (HMT) when this pump is at a flow rate equals to zero.

  The position of the tank must permit as far as possible that the chosen pump is both able to compensate the dynamic pressure losses and the static ones. The lowest the static head is the shortest time will be required to fill in the circuit when the primary loop pump is activated.
- The used P1 pump is an air cooled engine pump (not flooded engine pump) so as to be efficiently able to elevate the fluid into the top of the collectors. Its electrical power is identical to the one required in a similar pressurized circuit in all cases when the height difference between the highest point of the circuit (top of solar collectors) and the drainback tank is less or equal to the pressure losses when the circuit is running nominally (dynamic pressure). This rule is practically corresponding to a four level building with solar collectors on the rooftop and a drainback tank located on the top of the technical room in level zero, and overall pressure losses along the circuit estimated to nearly 1 bar (average observed value for a 100 m² solar collector system).

2.4. Main assets oft he drainback technology

The most interesting advantages of this technology are following:

- Total lack of risk of fluid vaporization including in case of dysfunctionning (power failure…)

- Simplicity in installing if the above exposed rules are respected. It is to note that it is not necessary to systematically impose a regular slope for the main piping connection from the collectors to the heat exchanger, especially if the fluid is still an antifreezing one.

Fig. 4: Example of a « high point » case in the main piping connection in a drainback system for an hotel in Villefranche sur Saône (« high point » level lower than the one of the lowest part of the solar collector field)

- Withdrawal of components considered as sensible elements for long term system reliability such as air vents, expansion vessel, non return valve…

  The safety valve should be however used in case of mistake when filling the circuit after years. This valve is considered as the ultimate safety organ, in case of entirely filling the circuit with fluid (non respect of the filling procedure)

- Primary circuit filling procedure avoiding :
  - to check the nitrogen pressure of the expansion vessel,
  - to do the circuit venting,
- Decrease of leakage risks (the system is not pressurized)
- Better reliability
- Operation and Maintenance action decrease with easy possibility to stop the system and the pumps at any time (including during sunny periods which is critical for a pressurized system) without the need to drain the collector field.
- System especially adapted to sporadic use applications (such as sport halls or center, school which always include holiday periods without DHW use…)
- Reduced investment costs due to the absence of some components (expansion vessel) when the technology is well known (the installer does not lose time when installing the solar collector field and the piping because knowing how to proceed) and above all operation costs (due to the extreme simplicity and reliability of the system)
- Similar or slightly better performance level than a traditional pressurized system, especially when the production is bigger than the needs for several days because there is no obligation to cool down the storage to avoid overheating.

2.5. Sensible points for the drainback technology

The weak points of this technology are detailed below and mostly represent minor ones when the technology is mastered:

- The technology is not adapted for cases where the solar collector field must be below or at the level of the technical room and with non drainable collectors.
- The relative higher investment cost level in case of no know how in installing such a technology mainly due to the large time necessary to install the collector field if not well planned
- Some potential difficulties for balancing the solar collector field in case of important difference of pressure loss between the batteries. Indeed, the presence of air in the loop is complicating the process of balancing therefore it is advised to use nearly batteries with similar internal pressure losses
- Requirement to make an air proof primary loop even if the system is not pressurized. This requirement is to avoid oxygen entry when the system is in slight depression (ambient pressure slightly lower than the system pressure) and then partial oxygenation of the circuit

After presenting the drainback technology, it is important to show the positive practical results obtained for now 10 years in numerous real installations in installations.

3. Practical experience through existing drainback installations

3.1. Census of existing drainback systems designed by TECSOL

Convinced by the accuracy of the concept, the engineering office TECSOL has designed 40 installations using for 10 years now (see Table 1) using the drainback technology (collective dwellings, hostels, health sector, swimming pool heating, solar cooling and heating installation). Among them, 21 are automatically monitored through a detailed measurement protocol. Thanks to monitoring system included into the control device on site, it is possible to measure and store on the basis of 10 minute periods values for:

- useful energy produced (thanks to the C1 flow meter, TSS (outlet solar tank temperature) and TEF (cold water temperature))
- average temperatures for TSS, TEF, TSC (solar collector field temperature coming back to the technical room) and TBB (low part solar tank temperature) and the system performances thus can be evaluated.
- states (ON/OFF) of the two pumps P1 (primary loop) and P2 (secondary loop)
- solar global irradiance value SE.

A remote centralised managing and supervising system located in Perpignan in the head office of TECSOL is getting all the monitored data from all the systems sent by RTC or ADSL phone lines. All these data are then stored and analysed so as to detect eventual potential issues or more simply to establish energy balances available online for the customer in the TECSOL website (www.tecsol.fr/fr/SolterResAc.htm). For smaller solar systems, a smaller monitoring system can be installed: it is not permitting to have an automatic monitoring but thanks to a energy counter, it is possible on site to measure and periodically observe the efficiency and performances of the system (it is the case for 19 installations among Table 1.).

The Table 1 shows that the average solar collector area is of 60 m² for a total of 2 325 m² for the total installed solar collector area. After the first installations in 2001 and 2002, this is really from 4 years now (2007-2011) that the drainback technology has been widely promoted and installed among projects where TECSOL was responsible for the design and planning.

A wide variety of applications are represented with a majority of them using antifreezing fluid: this choice has been done especially to integrate numerous solar collectors from different manufacturers without freezing risks.

Tab. 1: List of existing French drainback solar systems engineered by TECSOL in 2011

Town	Building type	Running since	Collector area (m²)	Heating fluid type	Monitoring type
Castres (81)	Sport hall	2001	16	Antifreezing	Manual/local
Castres (81)	Sport hall	2001	14	Antifreezing	Manual/local
Toulouse (31)	Dwellings	2002	35	Antifreezing	Manual/local
Marrakech - Maroc	Hotel	2007	100	Water	Automatic/remote
Fes - Maroc	Hotel	2007	124	Water	Automatic/remote
Argelès sur Mer (66)	Camping	2008	22	Water	Manual/local
Argelès sur Mer (66)	Camping	2008	15	Water	Manual/local
Argelès sur Mer (66)	Camping	2008	20	Water	Manual/local
Fleury d'Aude (11)	Swimming pool	2008	28	Antifreezing	Manual/local
Argelès sur Mer (66)	Holiday center	2008	24	Water	Manual/local
Meknes - Maroc	Hotel	2008	98	Water	Automatic/remote
Bourges (18)	Hotel	2008	82	Antifreezing	Automatic/remote
Bort les Orgues (19)	Hospital	2008	93	Antifreezing	Automatic/remote
Cestas (33)	Nursing home	2008	112	Antifreezing	Automatic/remote
Pamiers (09)	Swimming pool	2008	122	Antifreezing	Automatic/remote
Oullins (69)	Hotel	2008	56	Antifreezing	Automatic/remote
Osséja (66)	Hospital	2008	88	Antifreezing	Automatic/remote
Paris (75)	School	2008	41	Antifreezing	Automatic/remote
Villeneuve/Lot (82)	Tertiary	2009	19	Antifreezing	Manual/local
Argelès sur Mer (66)	Camping	2009	16	Water	Manual/local
Argelès sur Mer (66)	Camping	2009	40	Water	Manual/local
St Médard/Jalles (33)	Restaurant	2009	23	Antifreezing	Manual/local
St Médard/Jalles (33)	Sport hall	2009	7	Antifreezing	Manual/local
St Médard/Jalles (33)	Sport hall	2009	14	Antifreezing	Manual/local
St Médard/Jalles (33)	Sport hall	2009	9	Antifreezing	Manual/local
Libourne (33)	School	2009	33	Antifreezing	Manual/local
Villefranche (69)	Hotel	2009	93	Antifreezing	Automatic/remote
Matemale (66)	Sport hall	2009	55	Antifreezing	Automatic/remote
Narbonne (11)	Dwellings	2009	37	Antifreezing	Automatic/remote
Issy Moulineaux (92)	Tertiary	2009	10	Antifreezing	Automatic/remote
Cadillac (33)	School	2010	19	Antifreezing	Manual/local
Trébas (81)	Nursing home	2010	30	Antifreezing	Manual/local
Portiragnes (34)	Camping	2010	23	Water	Manual/local
Meudon (92)	School	2010	7	Antifreezing	Automatic/remote
Ussel (19)	Tertiary	2011	250	Antifreezing	Automatic/remote
Pessac (33)	Dwellings	2011	192	Antifreezing	Automatic/remote
Albi (81)	Hospital	2011	78	Water	Automatic/remote
Nimes (30)	Dwellings	2011	47	Antifreezing	Automatic/remote
Toulouse (31)	Dwellings	2011	79	Antifreezing	Automatic/remote
Gradignan (33)	Dwellings	2011	154	Antifreezing	Automatic/remote

3.2. Selection of best practices

Among all the monitored systems, a selection has been achieved to present 4 specific systems which are well representing both application range for drainback and geographical repartition in the French territory. The Figure 5 shows in a French map where are located the four systems.

Fig. 5: Map for location of the 4 monitored systems in France

The systems are covering the following applications:

- Hotel in Bourges (Cher, Centre) : DHW production since March 2008
- Paramedical residence in Bort les Orgues (Corrèze, Limousin) : DHW production since 2008
- Collective dwellings in Pessac (Gironde, Aquitaine) : DHW production since December 2010
- Tertiary building in Perpignan (Pyrénées Orientales, Languedoc Roussillon) : air conditioning (heating and cooling) since July 2008

The main features and the performances level obtained are presented for each of them in the following paragraphs.

3.3. Hotel application in Bourges

This hotel is a two star one including 86 rooms. The domestic hot water production is made with solar energy and an electric back up (2 tanks of 3000 litres). The installed solar drainback system is composed of 82 m² flat plate collectors installed in a flat roof, facing South and with a tilt of 30°. A solar storage tank of 4000 litres and a 60 kW external heat plate heat exchanger are the main other components.

In operation since 2008, this installation has been fully monitored showing very good results for now more than 3 years (see Figure 6.). The measured production has been always above the guaranteed value (this guaranteed value itself is deduced from a calculation in the design phase including a safety margin of 20% and takes into account the real measured domestic hot water consumption). A specific focus can be done for Year 2010 (Figure 7.) with 30% exceeding the reference production (41 400 kWh measured), a total solar yield of 508 kWh/m²/year and a solar fraction of 70%.

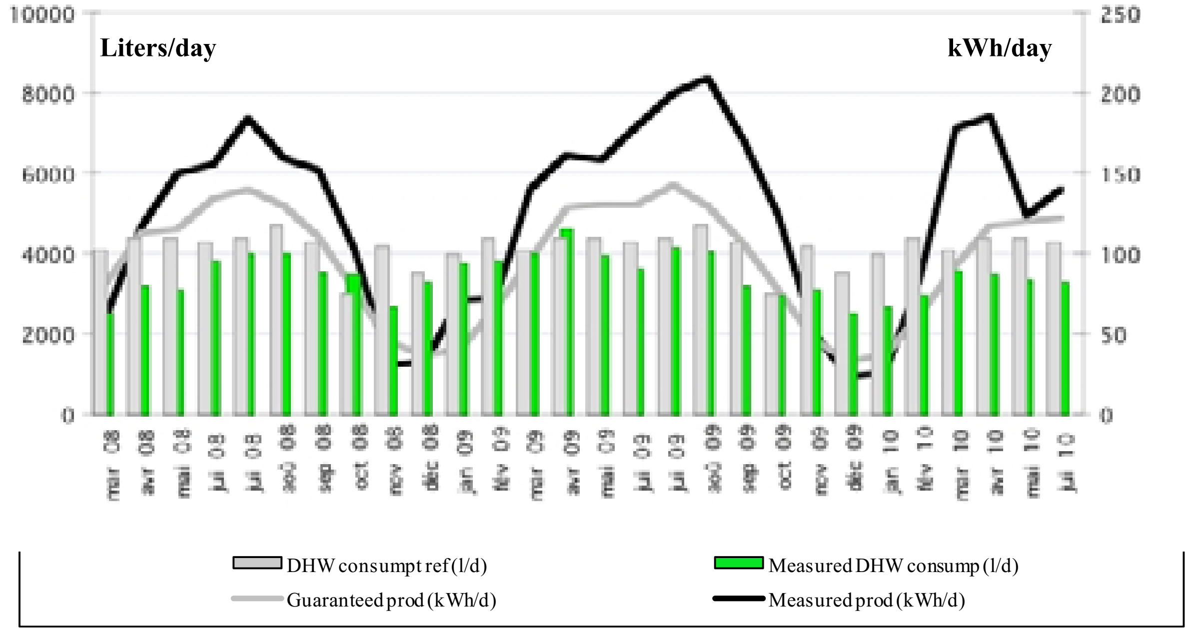


Fig. 6: Three year cumulated monitored values for hot water consumption and solar energy produced in comparison with reference values

DHW reference consumption (liters/day)	Measured DHW consumption (liters/day)	Guaranteed production (kWh/day)	Measured production (kWh/day)	Ratio Production (measured/ guaranteed)
4 138	3 067	87	113	130.3%
Ratio Consumption (measured/ reference)	**Solar fraction**	**Solar yield (kWh/m2)**	**Annual production (kWh)**	**Avoided C02 emissions (tons)**
74.0%	70.2%	508	41 402	5

Fig. 7: Performance indicators for the Hotel in Bourges for the Year 2010

3.4. Paramedical residence application in Bort les Orgues

The system is used for heating domestic hot water for 80 persons and for a restaurant located inside the establishment. The hot water production is made with solar energy and an mixed electric (summer) / gas (winter) back up (2 tanks of 3000 litres). The installed solar drainback system is composed of 93 m² flat plate collectors installed in a flat roof, facing South and with a tilt of 30°. Two solar storage tank of 2 500 litres each and a 70 kW external heat plate heat exchanger are the main other components.

In operation since 2008, this installation has been fully monitored showing very good results. A specific focus can be done for Year 2010 (Figure 8. and 9.) with 36% exceeding the reference production (55 765 kWh measured), a total solar yield of 598 kWh/m²/year and a solar fraction of 43%.

DHW reference consumption (liters/day)	Measured DHW consumption (liters/day)	Guaranteed production (kWh/day)	Measured production (kWh/day)	Ratio Production (measured/ guaranteed)
5 850	7 981	127	153	136.0%
Ratio Consumption (measured/ reference)	**Solar fraction**	**Solar yield (kWh/m2)**	**Annual production (kWh)**	**Avoided C02 emissions (tons)**
120.0%	43.0%	598	55 765	16

Fig. 8: Performance indicators for the Residence in Bort les Orgues for the Year 2010

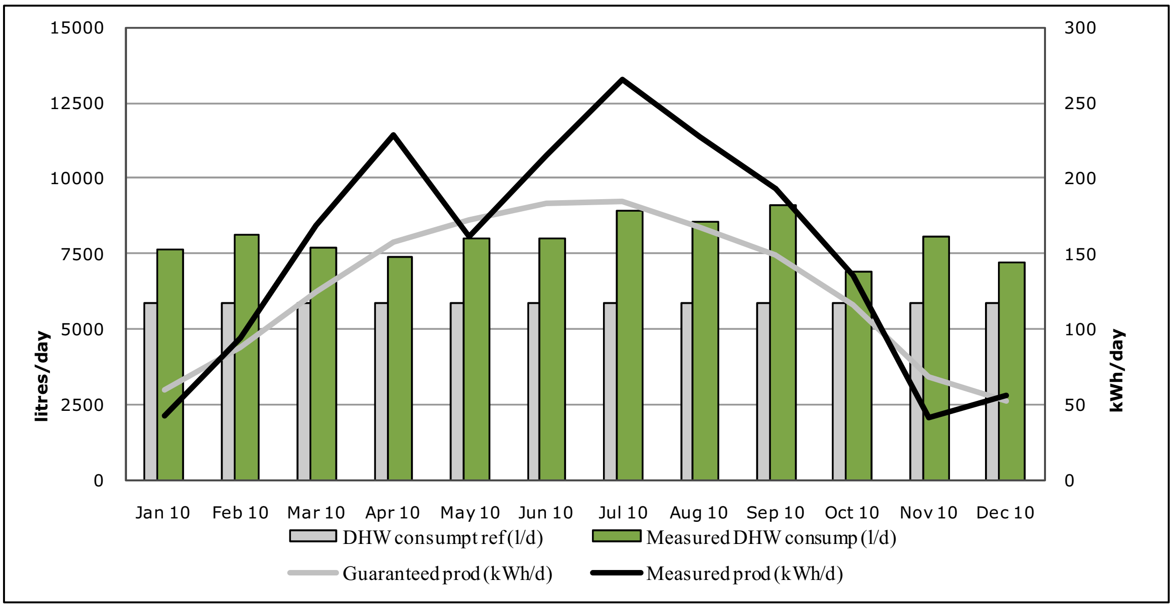


Fig. 9: Monthly graphical representation of the results for the Residence in Bort les Orgues for the Year 2010

3.5. Collective dwellings in Pessac

The system is used for heating domestic hot water for 360 apartments. The hot water production is made with solar energy and a natural gas back up. The installed solar drainback system is composed of 192 m² flat plate collectors (Figure 10.) installed in a flat roof, facing South and with a tilt of 30°. A solar storage tank of 10 000 litres and a 140 kW external heat plate heat exchanger are the main other components.

Fig. 10 : Solar collector field for the collective dwelling building in Pessac and drainback tank for the Hotel in Bourges

In operation since 2010, this installation has been fully monitored showing very good results for the first months of operation. A specific focus can be done for the first months of Year 2011 (Figure 11.) : it is showing that the measured production is significantly bigger than the guaranteed value, reaching even more than 540 kWh/day in April 2011 which was an exceptional month on the meteorological point of view in Aquitain area (South West of France). With an estimated value for the DHW needs of 880 000 kWh/year, the system should deliver nearly 130 000 kWh in 2011 (if keeping on giving the same performance level) which is corresponding to the high solar collector yield value of 680 kWh/m².year.

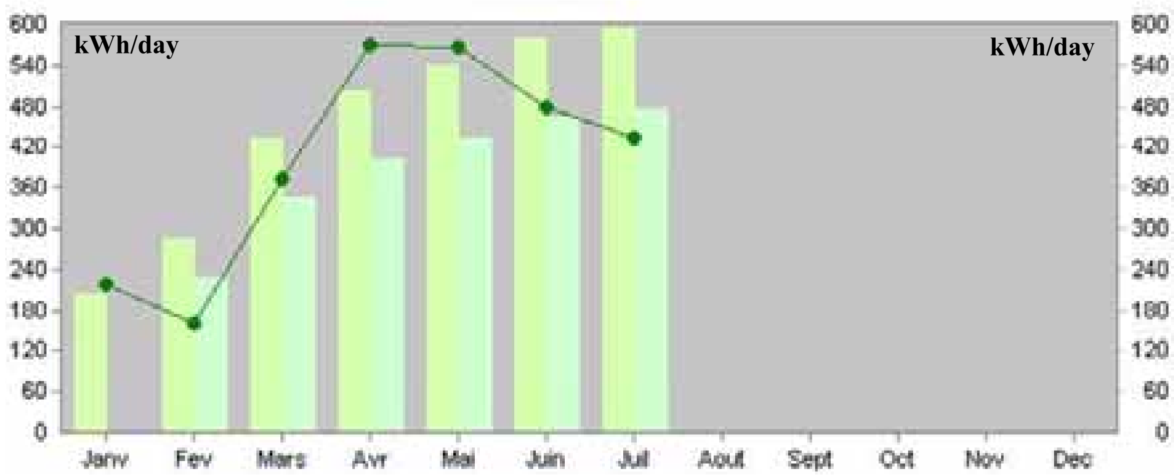


Fig. 11 : Monthly monitored performances (green curve with dots) in comparison with average calculated values (left histogram) and guaranteed ones (right histogram) for average daily solar energy production (kWh/day) in Pessac

3.6. Tertiary building solar cooling application in Perpignan

The targeted building welcoming the drainback solar cooling application is the CNRS PROMES research centre office. It is dedicated to research work and offices in the technical area TECNOSUD of Perpignan located in the Languedoc Roussillon area (South of France). The plant serves only a small part of a large building (administration office). The general orientation of the building is 45° towards the west (30° collector tilt angle) and the collector field is oriented in the same direction as the roof. The building was created in 2000 and is of good quality level for what energy efficiency concerns. The system is based on a 7.5 kW adsorption chiller coupled with 24 m² double glazed flat plate collectors (Figure 12.).


Fig. 12 : Double-glazed flat plate collectors and adsorption chiller installed at a laboratory/office building in Perpignan, France

The system is producing independently energy in parallel of a general multi split compression system (solar cooling system covers the base load and backup adapts the power to fit the load). The distribution system for the solar cooling system is an independent chilled/hot water network using 3 fan coils working at 14/18°C temperature level in cooling mode. The heat rejection system consists of a drycooler assisted by a spring water spraying device, only used in case of very hot days (more than 30°C ambient temperature).

Tab. 2: Monitoring results adsorption chiller in laboratory building

	May 2009	June 2009	July 2009	August 2009	Sept 2009	Average
Total electrical COP	5.5	4.7	4.6	4.0	4.4	4.6
Primary energy savings	49.3%	40.3%	38.8%	30.2%	35.8%	38.9%

The system has been working properly for more than 2 years in cooling and heating mode. The average total electrical COP has reached an average of 4.6 for the summer months (cf. Table 2.). In this period almost 39% of primary energy has been saved compared to a conventional compression cooling system that supplies the same amount of cooling. The building owner is satisfied of the solar cooling and heating system.

For a typical summer day of operation, the system provides cooling from about 10:30 am to 5 pm. It is to be noted that the temperature level evolution at generator side during the functioning period is totally following the solar irradiation while the condenser temperature level remains quite stable. The consequence of this behaviour is a quite good stability on the chilling capacity over the working period : this stability is mainly due to the fact the adsorption chiller used is not very sensible to temperature variation between 70 and 80°C in the generator loop (the heat exchange being nearly the same).

4. Conclusion

The drainback technology is one of the few solutions able to guarantee a long term durability, good performances, and low costs for the solar thermal installations and then offer an important growth potential for the actual low temperature solar thermal market.

5. References

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