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Storage and hot and cold water in a thermocline for Space heating/cooling and domestic hot water

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Abstract

Water thermoclines with heat pumps are used to store hot water for space heating (SH) and domestic hot water (DHW) needed for districts during winter time. The heat pump (HP) in the circuit, allows to discharge the thermocline up to a water temperature of 5°C (increase energy storage capacity). In summertime energy is needed to produce both domestic hot water and space cooling (SC). Usually these productions are separated. The thermal architecture proposed has as an objective to take fluid at medium temperature in the thermocline, heating up one part of this water in the heat pump condenser (going back on the top of the thermocline) and cooling down the other part of this water in the heat pump evaporator (going back on the bottom of the thermocline). A calculation of the annual energy consumption has been done for an application case with this technical solution compared to classical ones. Then the Return On Investment (ROI) of this technical solution has been carried out in order to identify the technical opportunity. It appears that for districts needing space cooling in summer time this solution has a very good ROI compared to usual solutions. Next step planned is to build a demonstrator to confirm the potential identified by this first theoretical study.

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Keywords : heat pump; thermocline; space heating/cooling

1. Context – Principle

1.1. Thermocline storage system

The functioning of a thermocline is similar to a domestic hot water tank. The objective is to store sensible energy in a tank by using a fluid and/or a material:

- To store energy hot fluid is introduced at the top of the Thermocline and cold fluid is rejected at the bottom of the tank.
- To discharge energy hot fluid is rejected at the top of the Thermocline and cold fluid is introduced at the bottom of the tank.

The hot water keeps at the top due to density difference. It order to avoid mixing between hot and cold water velocity in the tank must be low.

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This solution must be associated to a heat source with cost or availability which fluctuates over a day (ex. : solar energy, electricity) in order to maximize cost benefits.

Some applications for district heating exist in Europe. Among them there is Brest (France) and Munich / Crailsheim (Germany) which supply from 300 to 500 apartments.

The design of the thermocline must take into account constraints in order to have hot fluid separated from colder one. Good stratification increases the amount of energy available over a given temperature. For instance, for heating floor, only energy over 45°C can be used. Thus it is necessary to minimize fluid mixing, to maximize the amount of energy stored over 45°C.

1.2. Impact of the Heat-pump in a Water Thermocline storage system used for space heating and domestic hot water

During wintertime space heating temperature needed is from 65°C to 45°C depending on the heating exchange solution (high/low temperature radiators, heating floor…). Water coming back to the Thermocline is consequently over 40°C as presented in fig.1.

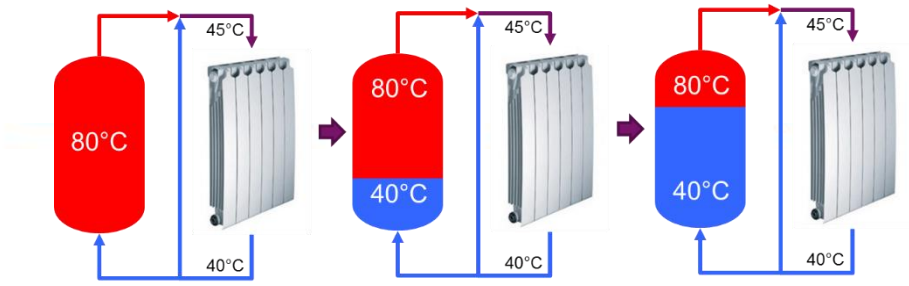


Fig. 1. Depletion of the thermocline with water return at 45°C

The benefit of the heat pump is to cool down water at the entrance of the thermocline from 45°C to 5°C (5°C to avoid water to freeze). The energy carried over is transferred to the water at the outlet of the thermocline, to heat up water. Consequently for the same energy stored the volume of the thermocline is highly reduced (due to the increase of the storage density).

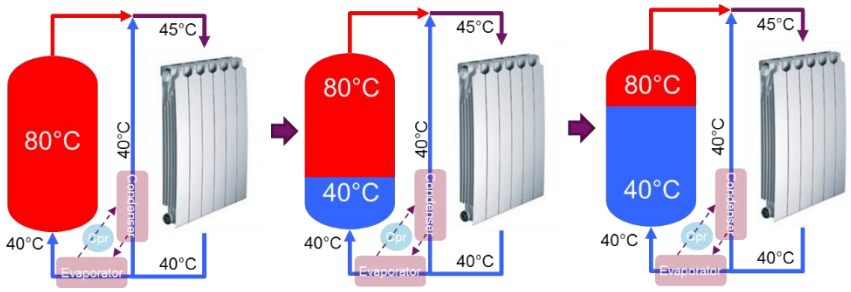


Fig. 2. Thermocline with heat pump; Phase 1: heat pump Off

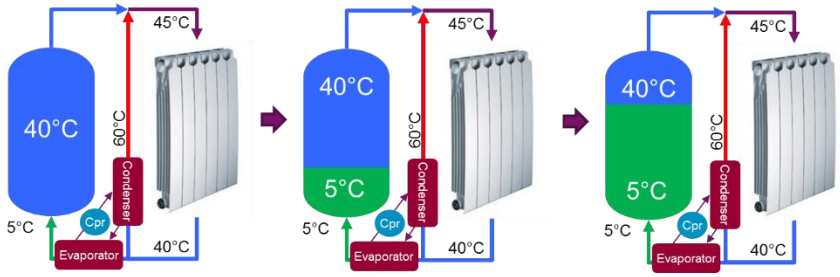


Fig. 3. Thermocline with heat pump; Phase 2: heat pump On

This technical solution has a cost benefit due to tank cost saving. Some applications uses this solution such as some solar district heating in Germany [1]. However, nowadays, this technical solution is usually more expansive than a gas boiler in many applications.

1.3. Heat-pump and Water Thermocline storage system for Domestic Hot Water and Space thermal regulation

The demand on a better comfort in building appears in winter and in summer time. Consequently the use of refrigeration increases. Two main solutions are available for refrigeration:

- System dedicated for cooling in addition to heating system (example : refrigerant loop in addition of a gas boiler)
- Combined system produces calories and negative calories (example : heat pump water/water)

In summer time the domestic hot water is realized by the condenser of the heat pump. At the same time the evaporator of this heat pump produces cold water. Traditionally these negative calories are thrown outside. However this cold water may be used for the building air conditioning. However needs of domestic hot water and space cooling don't occurs at the same time. Usually storage of calories and negatives calories are separated as proposed in references [2], [3] and [4]. But the thermocline may be used to store both calories for the domestic hot water and negative calories for the space cooling (as there is no calories stored for the space heating in summer-time). Space cooling may be available for instance by using cold water in an underfloor heating or low temperature radiators.

In summer time, the system behaves as follow for French application:

- Night (low cost of the kilowatt-hour): mid-temperature water from the thermocline is used to produce cold and hot water and store it in the thermocline.
- Day (low cost of the kilowatt-hour): hot water from the thermocline is used for the domestic hot water; cold water from the thermocline is used for the space cooling.

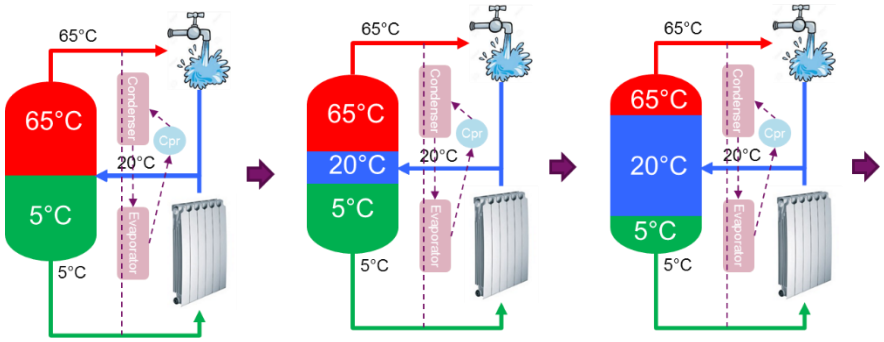


Fig. 4. Thermocline in summertime (Phase 1: day)

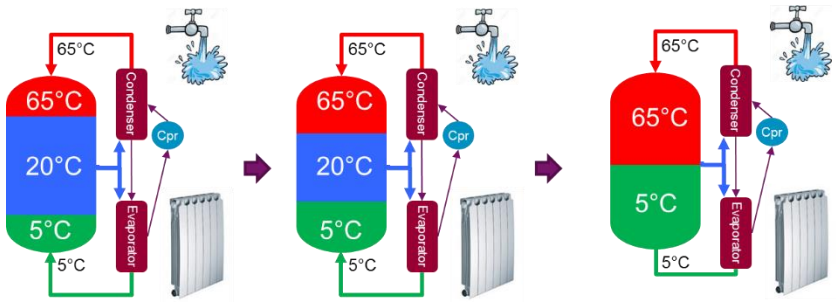


Fig. 5. Thermocline in summertime (Phase 1: night)

As a consequence an adaptation of a thermocline associated to a heat pump is a technical solution to deliver:

- domestic hot water all over the year
- hot water for space heating in wintertime
- cold water for space cooling in summertime

Further this presentation of the principle the next step were to design the system for a specific application, to identify additional risk to focus on and to compare its ROI with other solutions.

2. Study of the solution

2.1. Case study

Study has been done for a building of 12 apartments (floor surface of about 750m²) assuming hypotheses of consumption coming from French Technical Regulation 2020 (RT2020). The system has been designed in order to store daily winter thermal needs in north east of France (Strasbourg is the location). In wintertime thermal need is about 400kWh/day.

This configuration has been chosen because:

- such technology will not be available before 2020
- compared to an house, a building will have a lower investment per household for a same cost saving per year (reduction of ROI)
- in France electricity rate can fluctuate over a day (cheaper over the night), which presents an advantage for the use of a storage

2.2. Components solution and main technical risks

The technical solution must operate in several functioning modes as presented in Table 1 and figures 6, 7, 8.

Table 1. Example of functioning modes of the heat pump / thermocline

Life condition	Wintertime Heat storage (up to 80°C tbc)	Wintertime Active Heat discharge (up to 5°C)	Summertime Storage (hot/cold water 65°C tbc / 5°C)	Summertime Active cooling discharge (5°C)
AC loop Mode	Heat Pump	Heat Pump	Heat Pump	Refrigeration mode
Fluid heated up	Water from the bottom of the thermocline	Water for space heating / domestic hot water	Water at mid-temperature of thermocline	Ambient Air
Fluid cold down	Ambient Air	Water going back to the thermocline	Water at mid-temperature of thermocline	Water from bottom of thermocline
Thermocline	Water circulates downwards	Water circulates upwards	Water circulates from middle to the bottom and top	Water circulates downwards

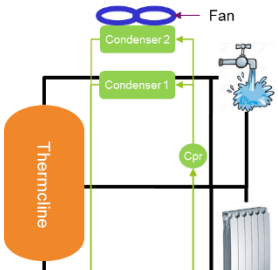


Fig. 6. Example of system

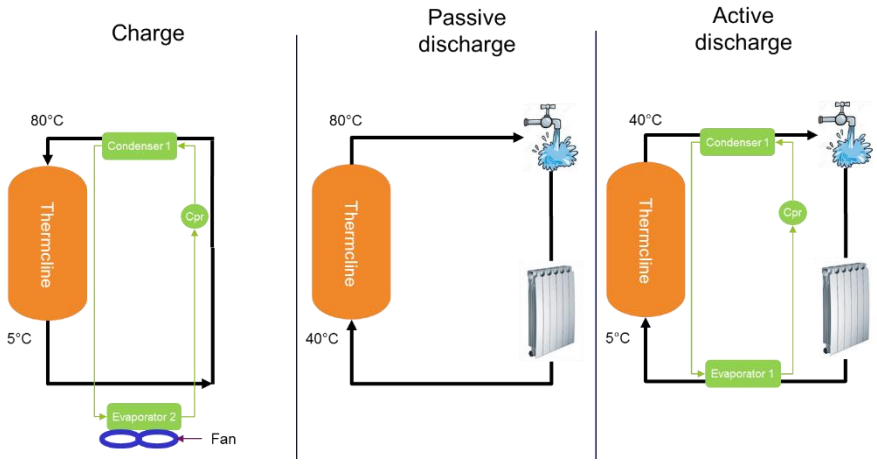


Fig. 7. Functioning modes in wintertime

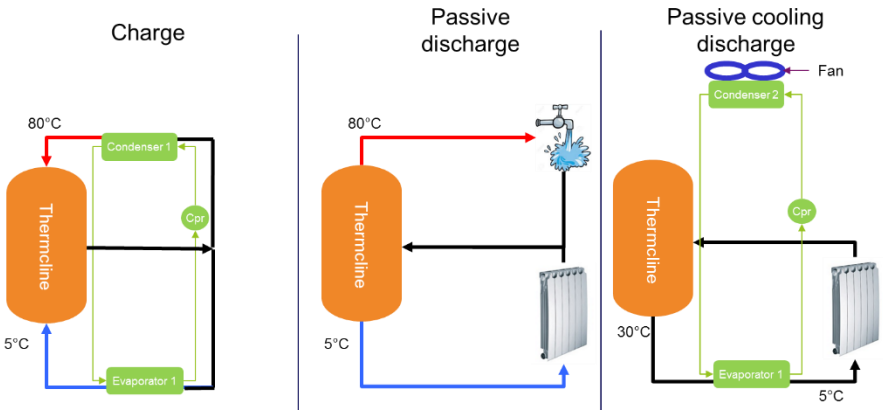


Fig. 8. Functioning modes in summertime

As observed the heat pump uses two evaporators and two condensers. For same functions, it may be possible to use a standard heat pump water/water with an adaptation of the water circuit (not presented in this document).

The main risk identified concerns the design of the thermocline. Usually hot water is introduced at the top of the thermocline and cold water introduced at the bottom. However in this application water may be introduced or taken at an intermediate temperature of the thermocline. For instance during storage in summertime it is necessary to take water in a mid-temperature area of the thermocline to inject it:

- at the top of the thermocline (hot water coming from the condenser)
- at the bottom of the thermocline (cold water coming from the evaporator)

As the water pumping location changes during the time it is necessary to identify a cheap solution for this function (study of the solution ongoing inside CEA).

2.3. Economical study

In order to determine the cost of this solution compared to reference one (refrigerant loop in addition of a gas boiler) it has been necessary to determine for the two solutions:

- Energy consumption / cost per year
- Investments

Evaluation of energy consumption has been done assuming 75 MWh per year of calories and 15 MWh per year of frigories. For this study a COP of the refrigerant loop of 3 has been used.
Cost of the energies are 2016 French market ones (from suppliers EDF and GDF). Notes that for the electricity, there is a difference of cost between day and night (-20%). Furthermore, an evolution of the cost of the gas and the electricity has been assumed according the French cost evolution during the 10 last years (+0,6%/year for the gas ; +4%/year for the electricity).

For this case study a numerical sizing of the system has been done. The Thermocline volume is lower than 3m3, and the heat pump thermal power at the condenser is lower than 40kW$_{th}$.

The costs of the heat pump, water pumps, valves, water tank, fans and gas boiler come from economical offers from suppliers. Once the investment for the thermocline/heat pump system has been determined, an economical participation of the French government has been deducted (-30% on the cost of the system).

The figure 9 presents the cost for these two solutions over the years.

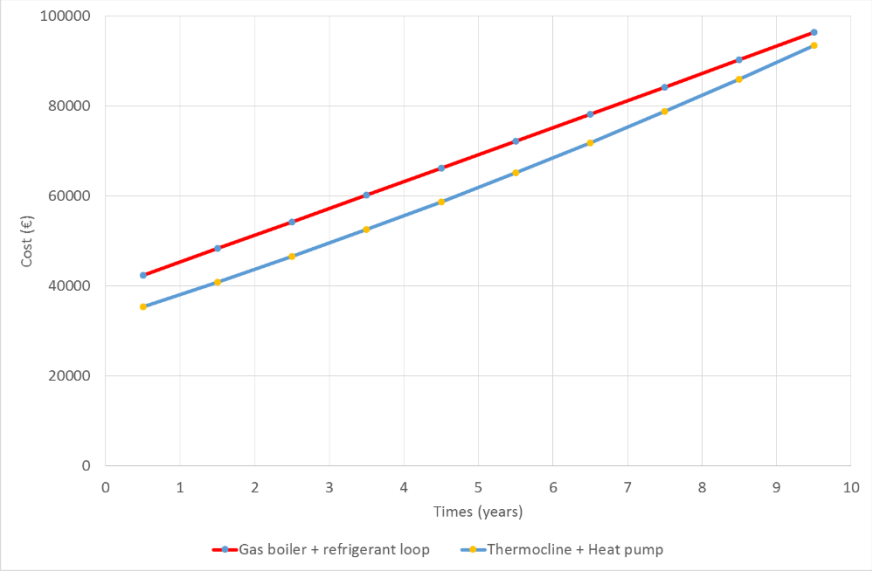


Fig. 9. Cost of the solutions

As observed in figure 9, the solution of using both a thermocline and a heat pump is the cheapest one. However it is specific to French market, with cheap electricity (<0,16€/kwh) and financial participation of the government for the heat pumps.

3. Conclusion

The solution of coupling a thermocline with a heat pump has been studied in this publication in order to deliver hot water / space heating in wintertime and hot water / space cooling in summertime. First the technical architecture, but also functioning modes and economical study. Study has been done for a building of 12 apartments in Strasbourg (France) assuming hypotheses of consumption coming from French Technical Regulation 2020.
This solution is economical to deliver calories and negative calories for a residential building in France.
Conclusion may be different in other countries. However other applications can be identified for such solution in the industry. Main technical risk of this solution is to guarantee the stratification in the thermocline with a suction or a discharge of the water not at the bottom and the top of the thermocline. At present time cheap technical solutions have been identified, but have to be experimentally validated.

Acknowledgements

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