Seasonal storage coupled to solar combisystem : dynamic simulations for process dimensioning

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Abstract

The objective of this preliminary study was to address the potential of thermochemical long-term storage coupled to standard CombiSystems available on the market. Thanks to high reaction enthalpy, chemisorption process enables compact long term storage without heat losses. By connecting storage process directly on buffer tank, annual solar fraction can be greatly increased. Dynamic simulations have been performed using thermodynamic simplified model for the storage process. Results lead to determine most profitable configuration among numerous interdependent parameters: thermal performances required for the system, collector area, storage volume, fractional energy saving objective, climate, building … Detailed analyses and parametric studies indicate the tricky points and some ways to optimise annual energy saving for various conditions. Reactor performances are important; salt selection, heat and mass transfer of the reactive layer are essentials. And parameters that concern global process, such as geothermal temperature, have huge influence also.

1. Introduction

The European Union has set the target for increasing the share of renewables in energy use to 20% by 2020. In EU 27, low temperature heat represents 34% of the total final energy consumption (transport included) and 61% is dedicated to household [1]. So dwelling heat represents 2830 TWh. It means that building insulation must be improved as well as solar thermal applications. Indeed, there are only three renewable sources available to provide heat (biomass, geothermal and solar) and fractional energy saving of solar combisystems is usually limited to 20 or 30%.

A way to increase solar fraction is to integrate seasonal thermal energy storage. This paper deals with the development of thermo-chemical storage process and its connection to existing facilities. This preliminary study is dedicated to the evaluation of global performances and to the design of the system. Dynamic simulations have been performed using thermodynamic simplified model for the storage process. Results lead to determine most profitable configuration among the variety of interdependent parameters: thermal performances required for the system, collector area, storage volume, fractional energy saving objective, climate, building … And detailed analyses of parametric studies help for dimensioning the process.

2. Thermochemical energy storage: solid-gas reaction for compact long term storage

2.1. Closed process: 2 endo/exothermic reversible reactions in parallel

Reactant salt is hydrated (A) or dehydrated (B) and water is condensed or evaporated. Chemical equations can be written as follow where ΔHr and L_{vap} are respective reaction energy:

$$A + \Delta Hr \leftrightarrow B + \nu\, H_2O_{vap} \qquad\qquad H_2O_{vap} \leftrightarrow H_2O_{liq} + L_{vap}$$

Figure 1 shows thermodynamic equilibrium diagram and the seasonal phases corresponding. Thanks to solar energy, vapour is extracted from salt. When necessary, vapour is provided to salt to release energy. An evapo-condenser thermally linked to geothermal source enables water transfer. This study concerns an integrated reactor composed of reactive layers constrict between a gas diffuser and heat exchanger (see fig 1 (right) [2])

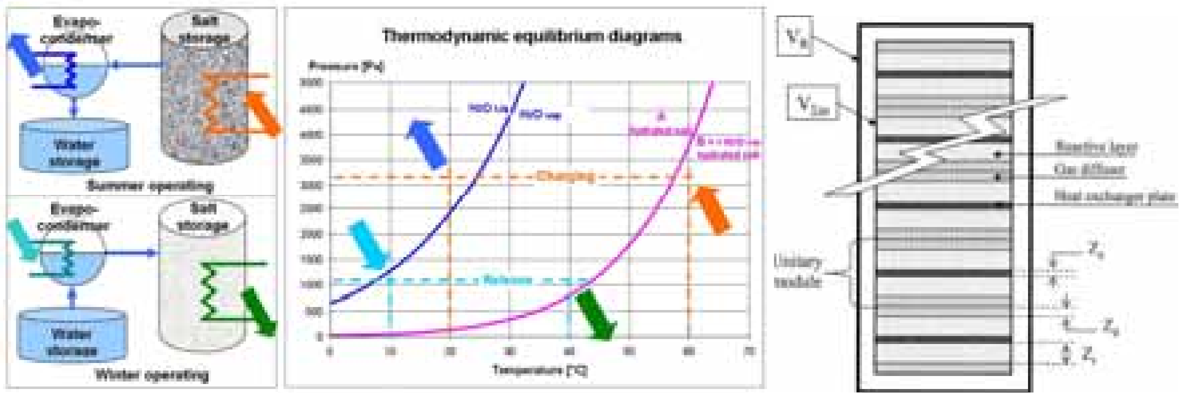

Fig. 1. Chemisorption storage principle (left) and reactor design principle (right)

Contrary to adsorption (also called physisorption [3]), thermochemical reactions (or chemisorption [3]) is monovariant. It means that thermodynamic equilibrium is independent from storage charging state; equilibrium temperature is only linked to pressure (and vice versa).

2.2. No heat losses during energy storage period and high energy density

Components are stored separately at ambient temperature. Advantage of chemisorption is that temperature release does not depend on charging state and energy density is very high, more than 600 kWh/m^3 related to the salt volume [2].

2.3. Selection criterion for Thermochemical material

Salt selection has to take into account thermodynamic equilibrium (Temperature and pressure compatible with operating conditions, see figure 1-left) and energy storage density. Corrosiveness, environmental impact, toxicity and cost of the material have to be considered seriously also.

3. Numerical modelling of storage process and its environment

3.1. Gibbs equivalent systems: 1D dynamic model for process simulations

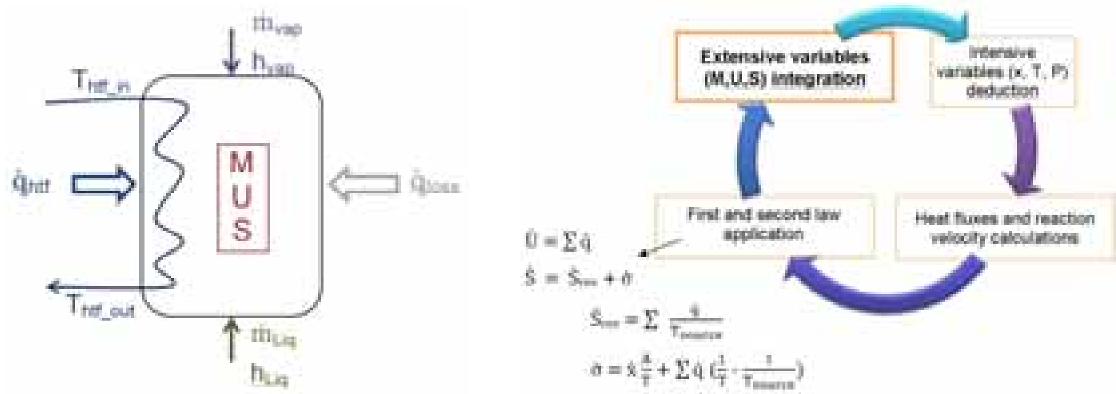

Fig. 2. Component modelling principle (left) and iterations steps (right) of Gibbs models

Storage reactor modules and evapo-condenser are simulated with the numerical modelling method developed by P. Neveu [4] and based on I. Prigogine works [5]. In Gibbs equivalent system, pressure and temperature are supposed uniform inside each component. Main particularity of this model is to integrate on extensive variables (M, Mass / U, Internal Energy / S, Entropy) instead of integrating on intensive variables (x, reaction progress / T, Temperature / P, Pressure) and it is more accurate for exergy balance (see figures 2).
Moreover, like thermodynamics conditions are not at equilibrium, reaction progress velocity is better taken into account which is essential for thermochemical and phase changing reactions.

3.2. Global parameters of the numerical model have to be correlated with experiments

Specific coefficients are used for each physical principle involved in the component: heat loss, heat transfer with the heat exchanger, mass transfer and reaction kinetic. They have been set to quite pessimistic values in order to identify difficult points.

3.3. Solar collectors, buildings and DHW draw-off issued from IEA-SHC Task 32 standards [6]

Flat plate collector slope is 45° and its efficiency coefficients are $\eta_0 = 0.8$, $a_1 = 3.5$ W/m².K, $a_2 = 0.015$ W/(m².K²). Buildings simulated are SFH100 and SFH15 that correspond to 140m² single family houses with space heating loads of, respectively, 100 and 15 kWh/m²/year at Zurich. Hot water load corresponds to, in the mean, 200l/day consumption at 45°C with a realistic profile.
Geothermal source has not been modelled; it is taken into account through input temperature of the evapo-condenser. Its mean value is the annual mean value of ambient temperature (9,1°C in Zurich, 13,1°C in Carpentras) . Amplitude of 10°C is added because this geothermal source is cool down during winter and warm up during summer.

4. Integration to building existing system

4.1. Temperature constraints concerning collector and emitter

Flat plate collectors are more frequently used and our objective is to design a seasonal solar storage compatible with this technology. Taking this point into account, temperatures range of radiators are too hot whereas heating floor fit with thermochemical potential uses.

4.2. Coupling with existing Solar Combisystem

Preliminary study proved the necessity of short term storage due to daily lag between solar supply and heat need; so long term storage must be associated to buffer (water tank). We can see that auxiliary equipments required by long-term storage are included in solar combisystem.
Among variety of solar CombiSystems, most of the systems available on the market can be categorized [7] depending on DHW preparation (tank in tank system, immersed heat exchanger or fresh water unit) and integration of the auxiliary heating (integrated as return flow increase or only charging the water tank).
CombiSystem used in this study is presented in figure 4. Fresh water unit avoid sanitary matters and it is more and more use on current systems. Using water tank as buffer concerning auxiliary energy is simpler concerning control and plumbing. Storage units can also be easily connected to the buffer tank. However other solar combisystems types are also convenient.
Performances of solar CombiSystem designed have been evaluated using FSC method, issued from IEA-SHC Task 26 [8]. Interest of this method is to compare performances objectively. FSC means Fractional Solar Consumption and can be considered as the maximum theoretical fractional energy saving. Fsav represents the fractional thermal energy saving, (Eauxiliary-Eref)/Eref.

Figure 3 shows Fsav plotted on FSC for 3 configurations simulated and for 2 auxiliary boiler efficiencies. All other presentations correspond to 85% auxiliary boiler efficiency.

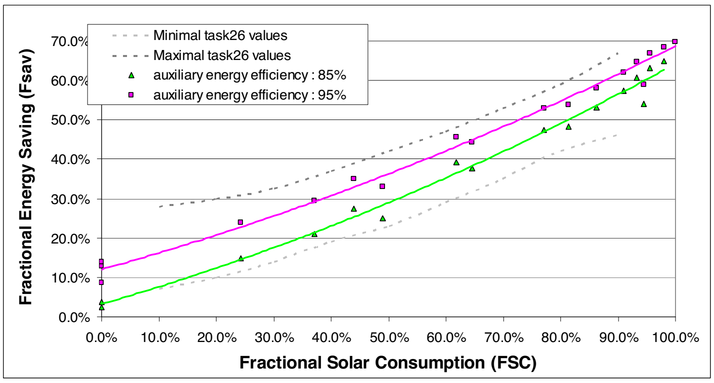

Fig. 3. Solar CombiSystem performances analysis

Curves fit with generic systems results of IEA-SHC Task 26. Performances of the solar CombiSystem designed are quite good whereas it wasn't the direct objective of the study.

4.3. Storage integration and its regulation

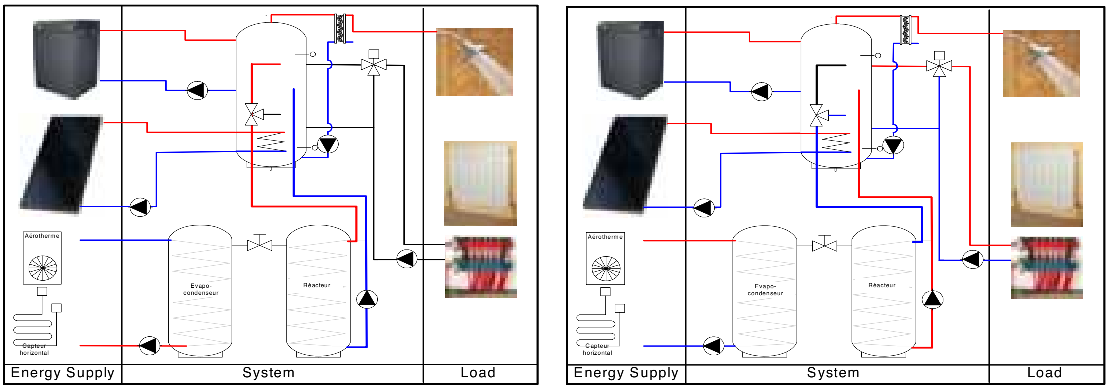

Fig. 4. Solar CombiSystems connected to storage in summer (left) or winter (right) mode.

Thermochemical reactor is thermally connected to water tank (see figure 4) and not to heating emitter. Thus, control is easier since storage process operates as auxiliary heater during winter and can naturally remove extra heat during summer. Concerning control strategy, boiler is either started for DHW needs or heating space needs. Heat is stored in the thermochemical storage when water tank is hot (T>60-80°C depending on season) and released when water tank temperature is less than 40°C. The process operates when load level is comprised between 5 to 80%; so only 75% of storage capacity is used what can be improved. The storage process simulated is modular; up to 3 modules can be installed, and modules can run consecutively or simultaneously.

5. Results concerning SFH100 building in Zurich with SrBr2 as thermochemical salt.

5.1. Interdependency between collector area, storage volume and energy saving

These three main parameters are strongly inter-dependants for dimensioning installation. Depending on storage cost, economic study could emerge most profitable couple.
Figures 5 show that Fsav reaches a plateau for constant collector area and reactive mass increasing, when all storage capacity is used. In the same way, there is a point where curve slope changes when reactive mass is growing and collector area constant. It corresponds to the optimum reactive mass

value which filling goes on all along summertime. Last graphics link parameters (storage quantity and collectors area) that lead to same Fsav. Depending on storage cost, economic study could emerge most profitable couple.

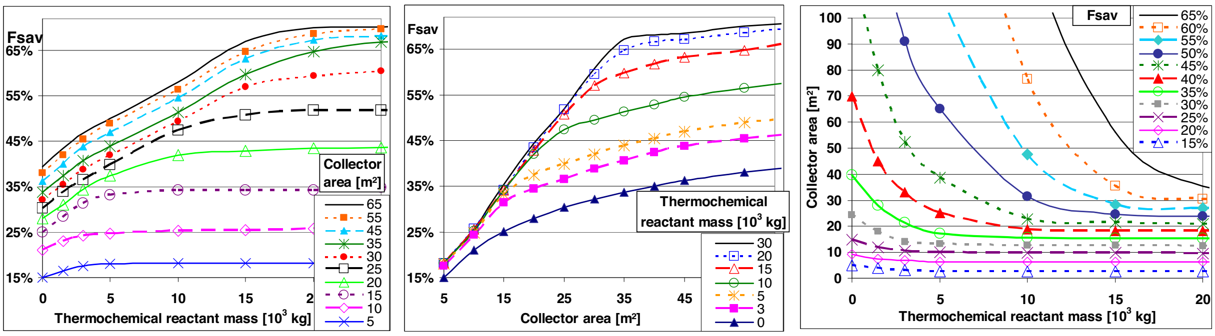

Fig. 5. Relations between Fsav, collector area and salt quantity for SFH100 Building in Zurich

Detailed analyses are necessary to understand and overcome Fsav limitations.

5.2. Energy balance

Graphics below present water tank energy balance of a simulated case with 30m² collector area and 15 tonnes of salt (of which 75% is used that represents 4000kWh). Energy values presented are useful energy; auxiliary efficiency is not taken into account.

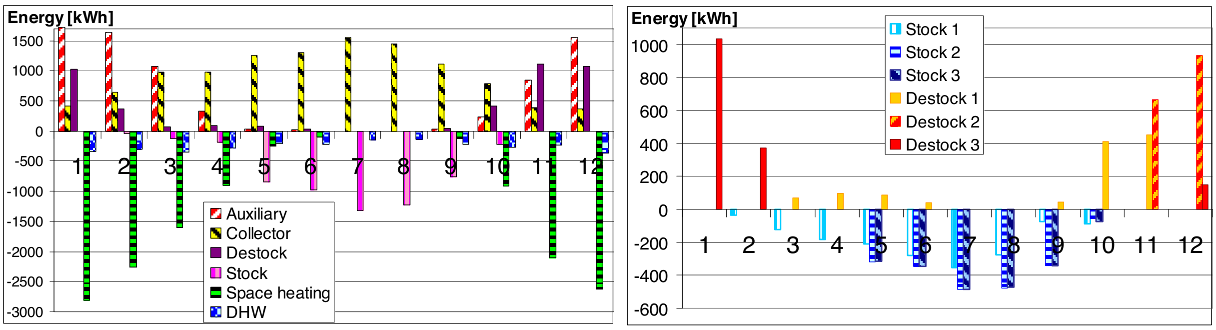

Fig. 6. Distrinution of monthly heating loads and supply (left) and storage modules charging and releasing (right)

5.3. Storage performances analyses

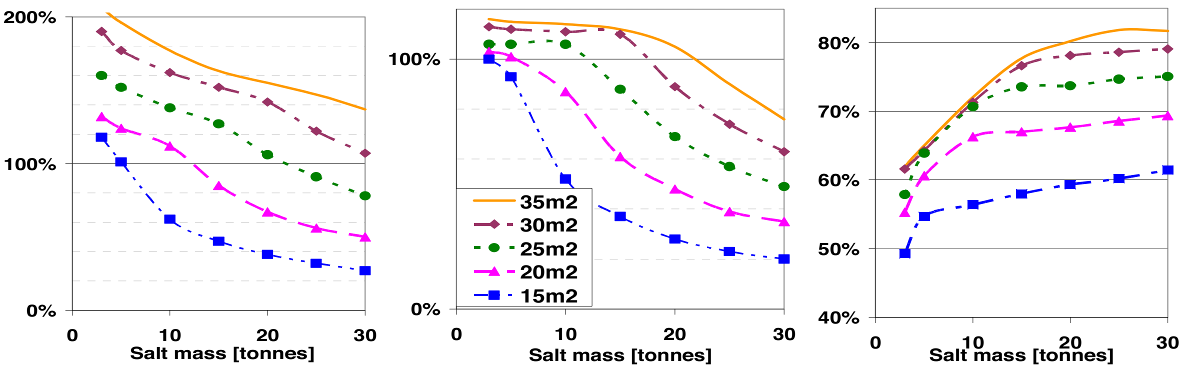

Fig. 7. Rate use of first module (left), of total storage (middle) and storage efficiency (right) in %

In figure 7, rate use represents energy released divided by effective energy storage capacity. Results analyses show that storage capacity is used more than once thanks to additional cycles (due to near load and release) that occur during spring and autumn. We can see that the couple collector area/salt quantity corresponding to total rate use of 100% corresponds to inflection points on the 3 graphics of figure 5.
Storage efficiency corresponds to the ratio between heat released from the chemisorption storage and heat charged. It is too low mainly because of heat loss during charging period. Solutions are proposed in paragraph 6.4.

6. Sensibility analysis

6.1. Climate and building

Simulations have been carried out with the same building (SFH100) for south of France climate (Carpentras) and another one under the same climate with very low consumption building (SFH15, 15 kWh/m²/year). Solar fractions are better since heat demands are lower.

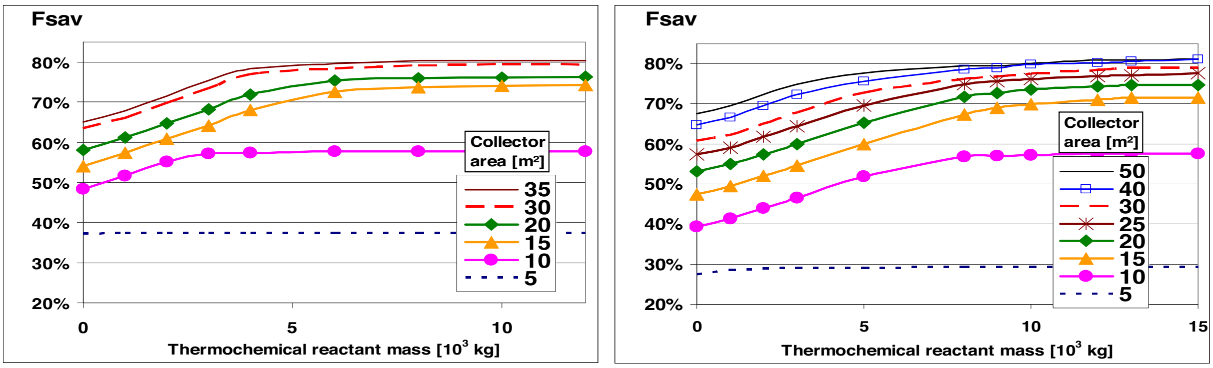

Fig. 8. Fsav vs. salt mass for SFH15 Building in Zurich (left) and SFH100 Building in Carpentras (right)

6.2. Power release analyses

In figures 9 to 11, Fsav and power distribution during release of energy are presented. These two results must be analysed in order to evaluate global performances. As storage process is connected with water tank and not with heating space system, control is quite simple and low power level can be used as pre-heating.

6.3. Heat and mass transfer influence

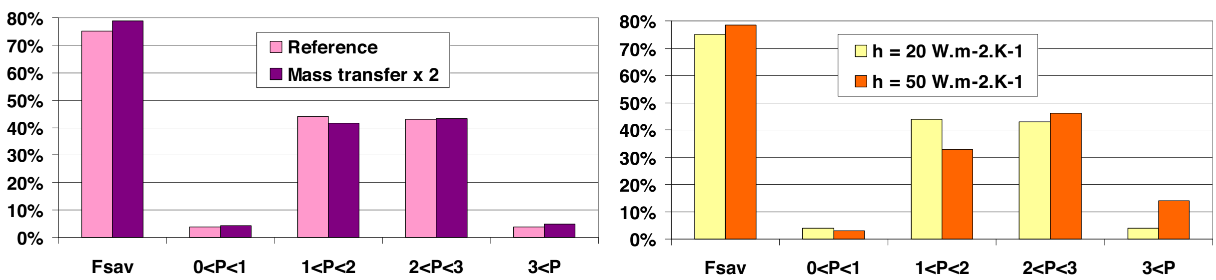

Fig. 9. Fsav and power release distribution depending on mass (left) and heat (right) transfer for SFH100 Building in Carpentras with 12t $SrBr_2$ and 20m² collector area

Reactor numerical modelling parameters have to be correlated with experimental study. As shown in figure 9, parametric studies have been performed to study the influence of the mass and heat transfer coefficients of the salt layer.

6.4. Salt, reactor insulation, geothermal temperature and rate use influence

• Some simulations have been performed with 3 theoretical salts of which equilibrium positions is presented in figure 10 (left). In the 3 cases, energy storage capacities are equivalent to 12t of SrBr2. Figures 10 (middle and right) show that salt equilibrium curve situated on the right lead to better performances. It confirms that releasing phase is more difficult than loading phase.

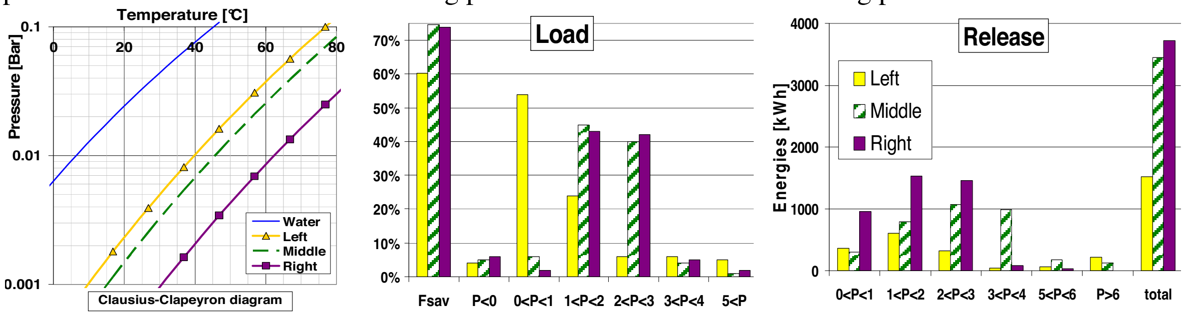

Fig. 10. Equilibrium salt position (left) and its influence (right) on Fsav and power charge and release repartition for SFH100 Building in Carpentras and 20m² collector area

• Except on storage efficiency, reactor insulation has little influence (figure 11-left). In the case simulated, only 140kWh are saved more because loading is finished in July whereas releasing begin in November so sensible heat loss is unavoidable. Thus it would be profitable to delay load phase when storage capacity is small. Other issue is to reduce storage module volume.

• Geothermal heat source temperature has a huge influence on energy saving and releasing power level (figure 11-middle). Increasing the size of ground-source heat exchanger represents a cost but it enables to reduce annual thermal amplitude and thus improve performances of storage process.

• Releasing power may be little at the end of discharging module phase, that's the reason why only 80% of the storage capacity is exploited in nominal case. Therefore, in the simulation in which 90% of the capacity is exploited, 2 modules operate simultaneously. Figure 11 (right) shows that 183kWh more can be saved without reducing power releasing level. For the same simulation case but with 5 tonnes of reactive salt, 250kWh can be saved more.

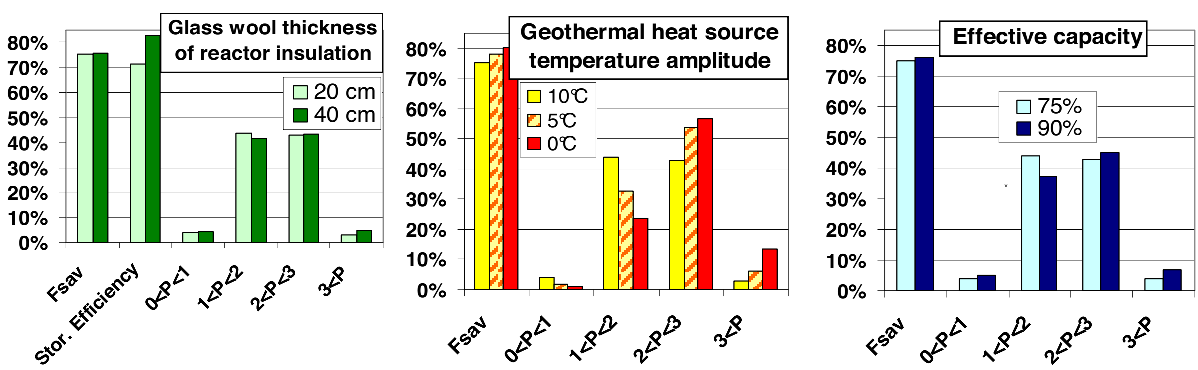

Fig. 11. Fsav and power release distribution depending on reactor insulation (left), geothermal temperature amplitude (middle) and effective capacity (right) for SFH100 Building in Carpentras with 12t $SrBr_2$ and 20m² collector area

• Other simulations show that water tank must not be reduced. Small term storage and long term storage are complementary and seasonal storage does not enables to reduce the buffer tank.
• Collector slope at 70° as been studied and lead to worst performances.

5. Conclusion

This preliminary study demonstrates the interest of coupling long term storage with solar combisystem, it is a way to increase solar fraction. Even with quite pessimistic values of numerical modelling parameters, dynamic simulations results bring hopeful conclusion. Power restitution level is lower than expected but storage process provides pre-heating that lead to interesting energy saving. Various ways to optimise annual energy saving are presented and also indications for selecting salt, sizing and controlling the process. Indeed there is no heat loss during storage period, energy density can be very high and temperature range is compatible with flat plate collector and dwelling heat demand.
Thanks to this preliminary study, the next step will be the design of a chemisorption storage unit together with CNRS/PROMES team, who has a significant experience for a long time on such systems.

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