# A Parametric Study of a Detailed Solar Combi-System Coupled to a Near Zero Energy Building

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## Abstract

Many control approaches have been developed for large solar collector fields but a few studies on Solar Combi-System ($SCS$) exist for domestic uses. This work presents a simple yet effective control algorithm for $SCS$ coupled to NZEB buildings using a feed forward cascade PID control. Existing works tend to use simplified simulation tools which do not account for efficiency enhancement contribution of a detailed control. Using *Modelica*, a dynamic control was coupled to a SCS and results show high performance even in harsh climate as Strasbourg. As shown in this paper NZEB should then consider solar energy for space heating too and not only as a way to provide domestic hot water.

## Introduction

In European Union, building sector is the highest energy consumer with more than 40 % of total final energy consumption of which 27 % for households. With global environment pollution issues, low consumption house and alternative energy such as solar can be a means to reduce $CO_2$ emissions and limit global warming. European Union agreed on the need to develop Net Zero Energy Buildings ($NZEB$) (EuropeanUnion (2010)) but implementation is country specific (Federal Ministry for Economic Affairs and Energy (2014); Laurent Reynier et al. (2014)). Conceptual goal is similar and can be defined as a balance between on site and grid resources (Igor Sartori et al. (2010), Karsten Voss et al. (2011)). With a favorable average solar irradiation in France (1112 kWh/m$^2$/year), solar systems can be a way to provide renewable Space Heating ($SH$) and Domestic Hot Water ($DHW$) (European Environment Agency (2012)). Yet an overview of *IEA Task 40* and *Annex 52* work shows solar energy is mainly used to provide $DHW$. Solar thermal heating appears to be barely selected as an energy saving measure (Eike Musall et al. (2010)).

Some parametric studies which evaluate solar combi-system ($SCS$) have already been carried out. Some use simplified buildings models with tools like *F-chart* to evaluated $SCS$ performances (Yoann Raffenel et al. (2009); Georgios Martinopoulos and Georgios Tsalikis (2014); Georgios Tsalikis and Georgios Martinopoulos (2015)). Results from these studies do not account for building and system dynamics. Yet, simplified tools are not well suited to account for the dynamic of solar collectors especially with small $DHW$ energy demands (Cuadros et al. (2007)). Moreover in $NZEB$, building dynamic response and inhabitant behavior are important (Éric Vorger (2014)). A major effort was achieved through the *IEA Task 26* which developed different $SCS$. Annual performance and sensitivity analysis regarding main parameters were conducted (Task26 (2003)). Jens Glembin et al. (2012) also used dynamics building simulations but no informations were provided on the control used.

Common control algorithms turn On/Off the pump by means of an hysteresis on temperature difference between collector outlet and tank volume. Yet many authors point out that a more detailed control can lead to a performance improvement. Duffie and Beckman (1980) used a feed forward control using irradiation and exterior temperature to improve pump control. Kicsiny and Farkas (2012) highlight the importance of mass flow rate regarding solar collector efficiency and point out an improve differential controller can increase pump lifetime. Faezeh Mosallat et al. (2013) emphasize limitations of control based on fixed minimal outlet collector temperature compared to dynamic control instruction. Lygouras et al. (2007) developed a controller which combines fuzzy logic with a PID controller and an adaptive PID controller was also suggested (Singh et al. (2000)). PID parameters were dynamically updated resulting in an elegant solution which can fit to a wide range of operating conditions. More recently, a Model Prediction Controller ($MPC$) was presented to anticipate irradiation fluctuations and avoid instabilities due to quick temperature fluctuation in solar collectors (Ferhatbegovi et al. (2011)). A complete list of existing control algorithms used in solar fields can be found in Camacho et al. (2007).

As outlined, a good control algorithm allows to achieve improvements in solar system performance. In this paper, an innovative $SCS$ with a detailed control algorithm coupled to a $NZEB$ building is analyzed. Control approach can be defined as a feed forward PID cascade controller. A high level controller takes care of equipments activation (valves, pumps,...) and multiple PID coupled to variable speed pumps allows to dynamically adapt the SCS behavior to favor solar energy. Outside temperature is also taken into account through solar pipes losses and solar energy allocation is optimized based on priority rules. For the control to work, a dynamic simulation of the building response is needed and a monozone model was selected after comparison with a detailed multi-zone design. Modeling approach required a versatile tool and *Modelica* with *Buildings* library (Michael Wetter et al. (2014)) were chosen. First, building and boundary conditions are detailed. Then an overview of the $SCS$ and its control algorithm is presented. Lastly, results from parametric study are discussed.

## Simulation

### Modeling

*Modelica* language (3.2.2) and *Dymola* (2017, 64 bit) were used to develop and simulate all system elements : controllers, equipments, and the house. *Modelica* is an open source equation-based and object-oriented programming language ideally suited for multi-domain modeling. Its component-based approach allows to easily make changes in the system definition. It can be opposed to a block-based approach where inputs and outputs are causal. Simulations were performed using the Cvode integrator algorithm which best handles stiff problems.

### Indicators definition

As a reminder, system performance indicators such as fraction of solar heating, fraction of solar domestic water heating and solar efficiency can be defined as follows :

$$F_{SH} = \frac{Solar_{SH}}{SH}$$
$$F_{DHW} = \frac{Solar_{DHW}}{DHW}$$
$$Solar_{efficiency} = \frac{Solar_{yield}}{Solar_{potential}}$$

where $Solar_{yield}$ stands for collected and valued part of $Solar_{potential}$ and $Solar_{potential}$ represents available energy on panels. $Solar_{SH}$ and $Solar_{DHW}$ represent respectively the solar energy part for space heating ($SH$) and domestic hot water ($DHW$) consumptions.

### Building description

The studied building is a house of $98.4\,\mathrm{m}^2$ belonging to a family with two children (4 people) and envelope is detailed in Table 2. Ventilation flow rate is considered at $90\,\mathrm{m}^3\,\mathrm{h}^{-1}$ and reduced to $20\,\mathrm{m}^3\,\mathrm{h}^{-1}$ in inhabitant absence (French decree from October 28$^{\text{th}}$, 1983). Insulation is internal and the house is heated with a unique air flow system avoiding conventional heating equipments. Indeed, using air for $SH$ reduces investment cost and makes the building to respond quickly to occupants needs. Internal loads (Table 1) were defined with respect to the French building energy efficiency norm (RT 2012 (CSTB (2011)). Electro-domestic consumption in occupation is about $5.7\,\mathrm{W/m}^2$ (80 % convective) and reduced by 80 % ($1.14\,\mathrm{W/m}^2$) in absence. Lights consumption in other hand is defined as $1.4\,\mathrm{W/(m^2.K)}$ (42 % convective) and reduced by 50 % ($0.7\,\mathrm{W/m}^2$) from 10 am to 19 pm the weekend. Lastly, each inhabitant is assumed to produce 97.5 W (70 % convective). This value is the result of an area weighted sum from the multi-zone house model where night and day room internal loads are detailed. Only $DHW$ and $SH$ demands are covered in this study, cooling and comfort is not evaluated. A comparison between a monozone (*Modelica*) and a detailed multi-zone (*Energy Plus*) model showed very small differences in energy consumption predictions when only $SH$ is considered. For this reason, a monozone building model was adopted. In addition, crawl space and space under the rafter was also modeled to account for floor and ceiling boundaries.

TABLE 1 – *Annual house consumption (*$\mathrm{kWh/m^2}$*) for Bordeaux with* $19\,°\mathrm{C}$ *as heating set point.*

| **SH** | **Electro-domestic** | **Lights** | **People** |
|---|---|---|---|
| 11.4 | 28 | 3.4 | 27.2 |

TABLE 2 – *Building description of opaques constructions and windows (EN673-2011, RDH (2014))*

| **Parois opaques** | | | |
|---|---|---|---|
| | **U** W/(m$^2$.K) | **Area** m$^2$ | **U*Area** W/K |
| Walls | 0.174 | 91.17 | 15.864 |
| Floor | 0.110 | 98.40 | 10.824 |
| Ceiling | 0.123 | 97.06 | 11.938 |
| **Windows** | | | |
| | $\boldsymbol{U_w}$ W/(m$^2$.K) | **Area** m$^2$ | $\boldsymbol{U_w}$***Area** W/K |
| East | 1.2 | 1.94 | 2.328 |
| East | 1.6 | 3.43 | 5.488 |
| West | 1.2 | 3.24 | 3.888 |
| North | 1.3 | 0.57 | 0.741 |
| South | 1.6 | 5.15 | 8.24 |
| South | 1.2 | 1.62 | 1.944 |
| Horizontal | 1.5 | 1.35 | 2.025 |
| **Total** | | 303.93 | 63.28 |

### System description

Hydraulic part (Figure 2) is composed of two tanks, a buffer to store solar energy for later use and a sanitary tank to provide $DHW$. During daily hours,

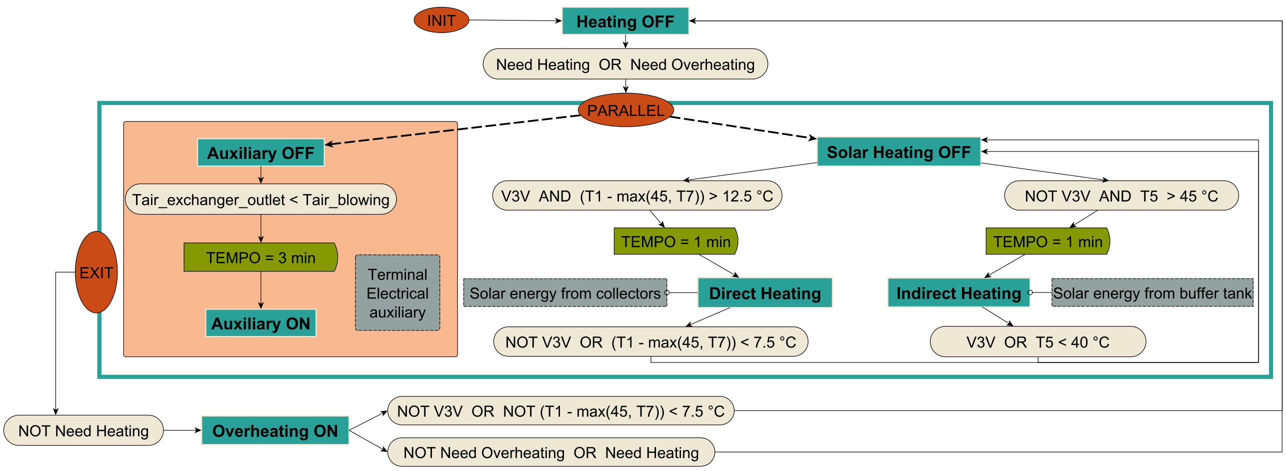


FIGURE *1 – Finite State Machine (FSM) used to control SH demand.*

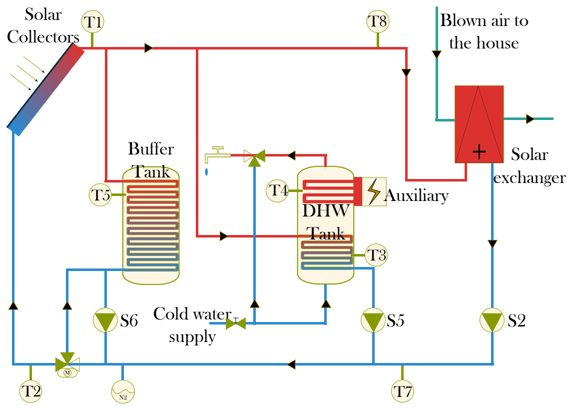


FIGURE *2 – Schematic description of the solar combi-system principle.*

solar energy is directly used to provide $DHW$ and/or SH and the buffer tank is loaded. Out of daily sun hours solar energy can be provided by buffer tank indirectly. That is, the fluid direction in the buffer tank exchanger depends on solar three ways valve ($V3V$) position. When the $V3V$ is opened toward solar collectors, pump S6 can be turned on. However, when $V3V$ is closed, S6 cannot be turned on and the flow direction in the exchanger is reversed (from bottom to top). Buffer tank energy can only be used to cover heating demand, $DHW$ demand is covered by solar energy stored in the $DHW$ tank. Lastly, when solar energy stock is too low, energy demand is covered by an auxiliary electric heater (Figure 1). A solution of 30 % ethylene glycol and 70 % water was used for solar system fluid in order to resist of exterior conditions for all climatic zones. Water thermal capacity is then reduced to 3608 J/kg.K.

SH system is modeled as an air handling unit composed of a water battery, an electrical terminal battery and a mixing box to reduce energy losses.

## Control algorithm

Hydraulic system uses pumps with variable speed to be able to optimize collected solar energy. As discussed in the introduction, common solar algorithm controls start solar pump when outlet collector temperature minus the target temperature (buffer tank, $DHW$ tank, ...) is bigger than a threshold. Then, pump stops when this difference falls below another threshold. This approach does not account for losses neither for collector efficiency. In this study a simple yet effective control is used. When a pump is activated its flow rate is defined to maintain at a minimum of 10 °C, the temperature difference between the collector outlet temperature and the target outlet temperature (exchanger) using a PID controller. This approach allows to dynamically account for losses and ensure a collector inlet temperature as low as possible leading to increasing collector efficiency. Meanwhile solar energy is shared between $SH$, $DHW$ and buffer tank energy demands, thanks to a cascade controller approach.

At a higher level, priorities are used to control how solar energy is dispatched. Priorities in order of importance are the following :

— Ensure at least 55 °C in upper part of the $DHW$ tank (S5).
— Keep up house air temperature at heating set point (S2).
— Ensure that $DHW$ tank bottom temperature is above a threshold of 30 °C before using solar energy to load buffer tank (S6).

That is, loading buffer tank is only allowed when the $DHW$ tank is already loaded up. This control approach can then be defined as a feed forward PID cascade control.

On $SH$ side, Air Flow Rate ($AFR$) and blowing set point temperature ($T_{air}^{ins}$) are variable (Figure 3). When heating is activated, $T_{air}^{ins}$ is set proportionally to the difference between inside and outside temperature. $T_{air}^{ins}$ increases dynamically until it reaches 32 °C

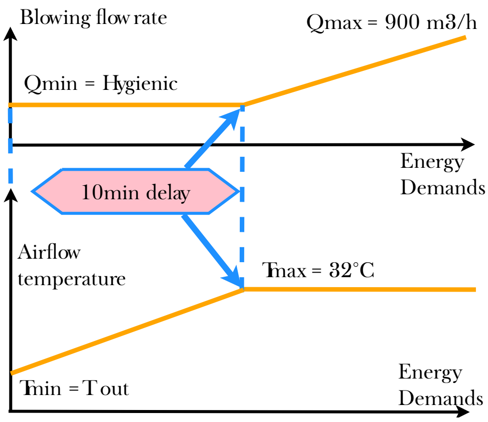


FIGURE *3 – Detailed description of SH air system control.*

while $AFR$ is set to the minimum hygienic flow rate. If needed, $AFR$ is increased to supply more energy. After 10 min, if $T_{air}^{ins}$ cannot be maintained by solar energy, an auxiliary electrical battery takes over. Controlling temperature and flow rate also allows solar energy to raise house air temperature and take advantage of house inertia to delay next auxiliary heating demand.

## Results

### Simulation procedure

In order to cover all climatic zones for France country, this study was conducted for 5 cities (Figure 4). A detailed analysis has been performed especially for Bordeaux and Strasbourg which represent respectively a favorable and unpropitious climates. In these analysis pump consumptions and pipe losses are both considered. Moreover, tanks (buffer and sanitary) are both in the house and their losses are also regarded. Parameter variations can be separated in two groups : schedule or profile variations and equipment modifications. The first group can be used to evaluate system performance for different boundary conditions, weather data (Table 4) and occupant behavior ($SH$ set point temperature and internal loads). The second group can be used to evaluate which factor more impacts solar combi-system overall performance and will help defining a set of indicators which can be used to characterize the system performance for further studies. In this group, panels azimuth and inclination, tank size, exchanger position, collector data and area variations are investigated. A reference solution is defined (Table 3). Without explicit mention, simulations assume these default parameter values.

### Climate impact

Table 5 summarizes $SCS$ performance on different climates. Electrical consumption includes pump consumptions. As tanks are inside the house, their losses are considered in $SH$ consumption since they participate in heating the house. It can be seen that

TABLE *3 – Reference solution detail.*

| **Parameter** | **Reference** |
|---|---|
| Buffer tank volume (l) | 300 |
| $DHW$ tank volume (l) | 300 |
| Collector type | IDMK 25 (8) |
| Collector Area (m$^2$) | 2.32 × 4 |
| Collector Tilt (°) | 33 |
| Collector azimuth | Sud |
| $SH$ set point (°C) | 19-18-16 (6) |
| Ventilation (m$^3$/h) | 90 (20 in absence) |
| Drawing Up (l/h) | EN12977 schedule(5) |


FIGURE *4 – Evaluated cities spacial allocation.*

solar system performance is high even for unpropitious climates as Strasbourg . The $SCS$ is able to cover $SH$ and $DHW$ with small auxiliary consumption. Moreover it can also be noted that $Solar_{yield}$ is high for all climates and $Pipe_{losses}$ and $Solar_{yield}$ relate. Actually, $Pipe_{losses}$ mostly depends on collector area and $DHW$ on tank volume. Hence $Pipe_{losses}$ are only slightly affected by the weather conditions. Minimal $F_{SH}$ and $F_{DHW}$ are unsurprisingly smaller for Strasbourg where degree days and irradiations are low.

Annual simulation have also shown electrical consumption during summer can be neglected (0.01 kW h/m$^2$ in the worse case). Simulation will then be performed only from 1st October to the 30th April and following results will only be discussed for this period.

### Set point temperature and internal loads impact

Different scheduled configurations for $SH$ temperature set point have been evaluated. Reference simulation schedule is defined as 19-18-16 with the following structure : Occupation (day) - Occupation (night) - absence. Variations for the structure can be

Table 4 – *Climatic zone description*

| | | **Bordeaux** | **Nantes** | **Strasbourg** | **Limoges** | **Marseille** |
|---|---|---|---|---|---|---|
| Cold water temperature (°C) | Min | 8.9 | 8.3 | 5.3 | 7 | 12 |
| | Max | 16 | 15 | 14 | 14 | 19 |
| Degree Day (19 °C) | | 2408 | 2660 | 3360 | 2972 | 2049 |
| Irradiation (kWh/m$^2$) | Global | 1264 | 1184 | 1091 | 1257 | 1545 |
| | Direct | 929 | 885 | 721 | 1209 | 1503 |
| | Diffus | 712 | 665 | 650 | 602 | 615 |

Table 5 – *Annual performance of the solar combi-system for different climate.*

| | **Consumptions (kWh)** | | | | | | | | | **%** | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Total** | | **Electrical** | | | **Solar** | | | | | |
| | $DHW$ | $SH$ | $DHW$ | $SH$ | **Pumps** | $Solar_{yield}$ | $Pipe_{losses}$ | $DHW$ | $SH$ | $F_{DHW}$ | $F_{SH}$ |
| Bordeaux | 2983 | 1024 | 101 | 91 | 7 | 3387 | 219 | 2444 | 949 | 95 | 91 |
| Strasbourg | 3180 | 1986 | 479 | 1203 | 8 | 3164 | 199 | 2332 | 845 | 83 | 42 |
| Marseille | 2784 | 975 | 2 | 1 | 7 | 3280 | 218 | 2300 | 974 | 100 | 100 |
| Nantes | 3044 | 1114 | 233 | 248 | 7 | 3295 | 209 | 2399 | 902 | 91 | 78 |
| Limoges | 3120 | 1311 | 217 | 359 | 9 | 3474 | 209 | 2502 | 983 | 92 | 73 |

Table 6 – *Allowed variations (gray) for* $SH$ *set point temperature (°C).*

<table>
<tr><th></th><th>16</th><th>18</th><th>19</th><th>20</th></tr>
<tr><td>Occupation (day)</td><td></td><td></td><td style="background:gray"></td><td style="background:gray"></td></tr>
<tr><td>Occupation (night)</td><td></td><td style="background:gray"></td><td style="background:gray"></td><td style="background:gray"></td></tr>
<tr><td>Absence</td><td style="background:gray"></td><td></td><td style="background:gray"></td><td></td></tr>
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found in Table 6. Following observation stands for Bordeaux but with less clear-cut variations. For this reason, only variations for Strasbourg will be presented in Figure 6. Increasing temperature set point in occupation period (19 to 20 °C) shows a 8 % increase in $SH$ consumption for electrical auxiliary but does not affect $F_{DHW}$. At the same time lower night temperature allows to reduce auxiliary consumption but does not affect the $F_{SH}$ and $F_{DHW}$. The solar system still performs well without reduced night set point temperature. On the other hand a constant value for temperature set point has a negative impact on the overall performance.

A constant ventilation airflow rate ($VentConst$) increases $F_{SH}$ part ($\approx +3\,\%$) but reduces $F_{DHW}$ ($\approx -1\,\%$) compared to a reduced airflow rate in absence. A reduced air flow rate increases auxiliary $SH$ consumption ($\approx +15$ kWh) but total electrical consumption decreases ($\approx -8$ kWh) due to a reduction of $DHW$ consumption. With a more important flow rate, the solar system is able to provide more energy for $SH$ but less to $DHW$ tank leading to this equilibrium. Lastly, internal loads cannot be disregarded when a $SCS$ is analyzed with a NZEB house.

### Tank volume influence

In this part, tank sizes (buffer and sanitary tanks) are picked between 150, 300 or 450 l and tank volumes are discretized in 20 segments to account for stratification (first segment is at the top of the tank). The solar exchanger position is relative to tank height which is volume dependent. Exchanger position ($ExchPos$) is picked from 0.8, 1, or 1.3 where 1 is the reference position at the 12th tank segment. A value of 0.8 forced exchanger to a lower position and 1.3 to an upper one with regard to tank height.

Increasing $DHW$ tank volume improves all three main indicators ($F_{SH}$, $F_{DHW}$, and auxiliary consumption) but auxiliary part for $SH$ roughly increases. In the other hand, a higher buffer tank size improves $F_{SH}$ and reduces auxiliary consumption as well as $F_{DHW}$. In both cases $Solar_{yield}$ is enhanced and tank temperature fluctuates slowly when tank size increases. Smaller volumes on both tanks negatively impact $SCS$ performance but larger size enhances the overall set of indicators. Yet, $DHW$ volume size is more important than buffer tank size and a $DHW$ tank volume of 450 l is preferred whereas a volume between 300 and 450 l seems to be sufficient for the buffer tank. Tanks size influence is more important when analyzed with climate of Bordeaux especially the electrical auxiliary consumption. This results also indicate that global $F_{solar}$ indicator is not impacted by the tank volume and $F_{SH}$ and $F_{SH}$ must be evaluated distinctly to be able to understand $SCS$ response. Moreover, exchanger material does not play a major role on $SCS$ performance for any indicator.

In contrast, exchanger position (Figure 8) inside the $DHW$ tank greatly impacts $SHS$ performance and is more significant when the tank volume is low. In both climate, exchanger must be at the lower position to improve $Solar_{yield}$ and auxiliary consumption even if an upper position slightly reduces auxiliary consumption for $SH$. It can be noted that exchanger position is more important for Strasbourg where auxiliary consumption potential cut is bigger. In brief,

TABLE 7 – *Variation of coefficients for each month and day (Coef) used to allocate DHW demand (ADEME (2016)).*

| Month | Coef | Day | Coef |
|---|---|---|---|
| January | 1.11 | Monday | 0.97 |
| Febuary | 1.2 | Tuesday | 0.95 |
| March | 1.11 | Wednesday | 1.00 |
| April | 1.06 | Thursday | 0.97 |
| May | 1.03 | Friday | 0.96 |
| June | 0.93 | Saturday | 1.02 |
| July | 0.84 | Sunday | 1.13 |
| August | 0.72 | | |
| September | 0.92 | | |
| October | 1.03 | | |
| November | 1.04 | | |
| December | 1.01 | | |

tanks size and exchanger position can be used to enhance the $SCS$ performance and it seems more appealing to increase $DHW$ tank and place the solar exchanger at the lowest portion of the tank.

### Drawing Up analysis

$DHW$ reference demand is defined based on 33 l/pers/day (at 40 °C) which is the mean value for French population (ADEME (2016)). Different profiles were studied to evaluate their impact on $SCS$ performance (see Figure 5). Only the distribution is changed while the withdrawn volume per day remains the same. $MoreMorning$ and $MoreEvening$ are symmetrical whereas *Split* profile assumes 3 identical peaks. Only the *Realistic* profile assumes more than 3 consumption peaks so as to be more representative of a standard $DHW$ profile. In order to account for realistic drawing up, weekly and monthly coefficients are also defined (Table 7) and their impact discussed.

Results for Strasbourg are presented in Figure 7. A realistic schedule slightly increases $Solar_{efficiency}$ but overall performance does not change with any of the examined schedules. Variation in inhabitant profile was also investigated through a thrifty (27 l/pers/day) and wasteful (40 l/pers/day) water usage. Results indicate that $SCS$ is robust as it was able to provide more solar energy to cover a more important $DHW$ energy demand. Indeed from a thrifty to a wasteful water management the $SCS$ $Solar_{yield}$ is increased by 248 kWh and auxiliary consumption by 390 kWh. As a result $SCS$ $F_{SH}$ and $F_{DHW}$ remain high. The use of monthly coefficients does not affect $F_{SH}$ neither auxiliary $SH$ consumption whereas reduced internal loads ($LowInternalLoads$) only affect $F_{DHW}$ and auxiliary $DHW$ consumption. As for tank volume variations these results highlight the importance of considering separately solar cover for $SH$ and for $DHW$. Lastly, $SCS$ performance is only slightly affected when Bordeaux climate is considered.

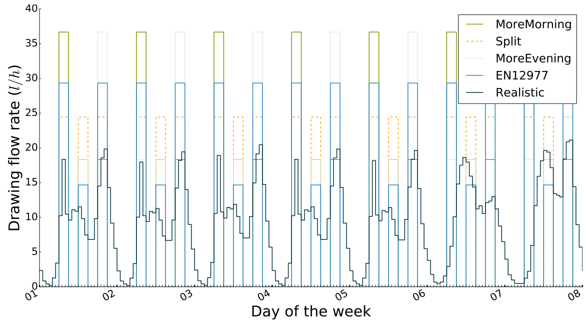


FIGURE 5 – *DHW demand profiles.*

TABLE 8 – *Solar collectors technical characteristics according to EN12975*

| | IDMK 25 | 308C HP |
|---|---|---|
| Manufacturer | *Sonnenkraft* | *Radco* |
| Type | Glazed - flat | Glazed - flat |
| Aperture area ($m^2$ | 2.32 | 2.193 |
| Maximum efficiency (% | 78.0 | 83.4 |
| slope | -5.103 | -4.777 |
| C1 ($W/(m^2.K)$) | 3.796 | 1.4539 |
| C2 ($W/(m^2.K^2)$) | 0.013 | 0.0589 |
| | **12 CPC58** | |
| Manufacturer | *SkyPro* | |
| Type | Tubular | |
| Aperture area ($m^2$) | 2.28 | |
| Maximum efficiency (%) | 63.0 | |
| slope | -0.975 | |
| C1 ($W/(m^2.K)$) | 0.9249 | |
| C2 ($W/(m^2.K^2)$) | 0.00069 | |

### Other variations

Panel tilt and orientation heavily impact $SCS$ performance and affect all indicators. Increasing collector tilt helps to reduce auxiliary consumption. Higher tilt also reduces solar energy in summer which can help to manage collector water maximal temperature. Collector area and azimuth are both important factors and can cause high variation in auxiliary consumption. At Strasbourg $F_{SH}$ can vary from 11 % to 52 % with a collector area between 4.6 and 18.6 m$^2$ and auxiliary consumption from 2232 to 1133 kWh. For instance, if all collectors are on the Eastern side of the roof, collector area must at least double in order to reach similar $SCS$ performance. Lastly, different configurations (Table 8) of collectors were evaluated and only slight variations were detected between them. The Glazed flat plate collector (Radco 308C HP) appears to give somewhat better results and tubular collector to be the worst even in Strasbourg.
In brief it appears that collectors for $SCS$ must only be added to South to perform well. If possible collector tilt must be greater than the location latitude ($\approx +15°$) to increase all indicators.

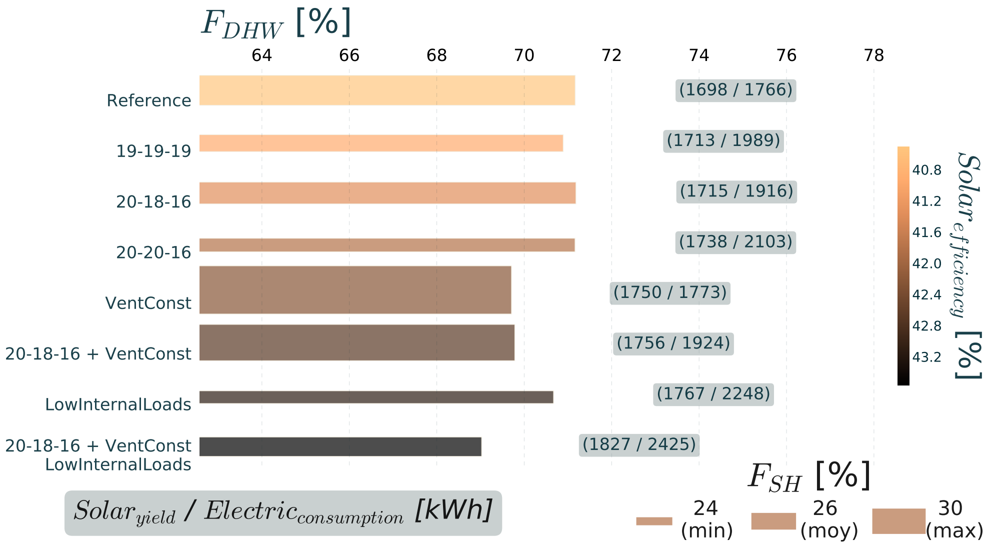


FIGURE 6 – *Impact of SH set point temperature variation on the SCS performance (01/10 to 30/04).*

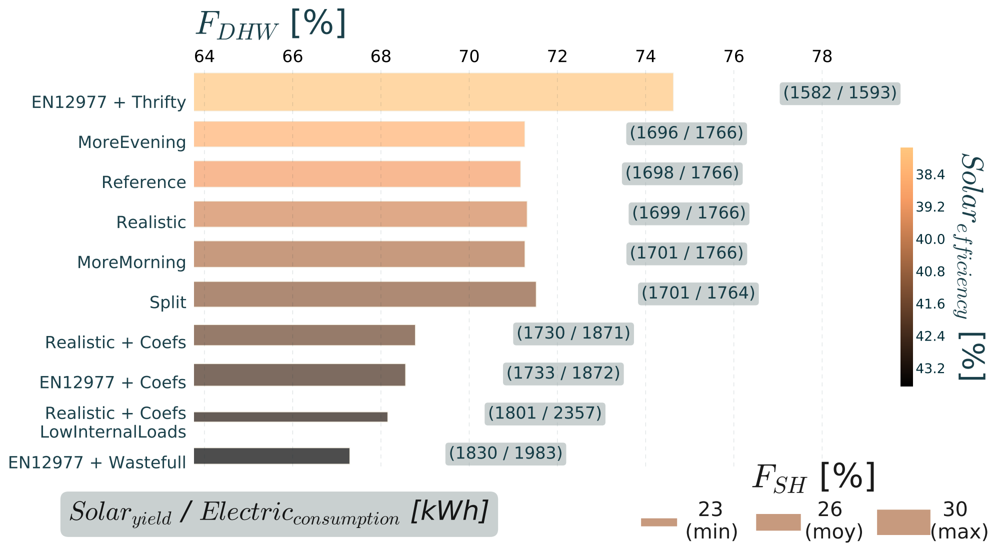


FIGURE 7 – *Impact of drawing up profile variation on the SCS performance (01/10 to 30/04).*

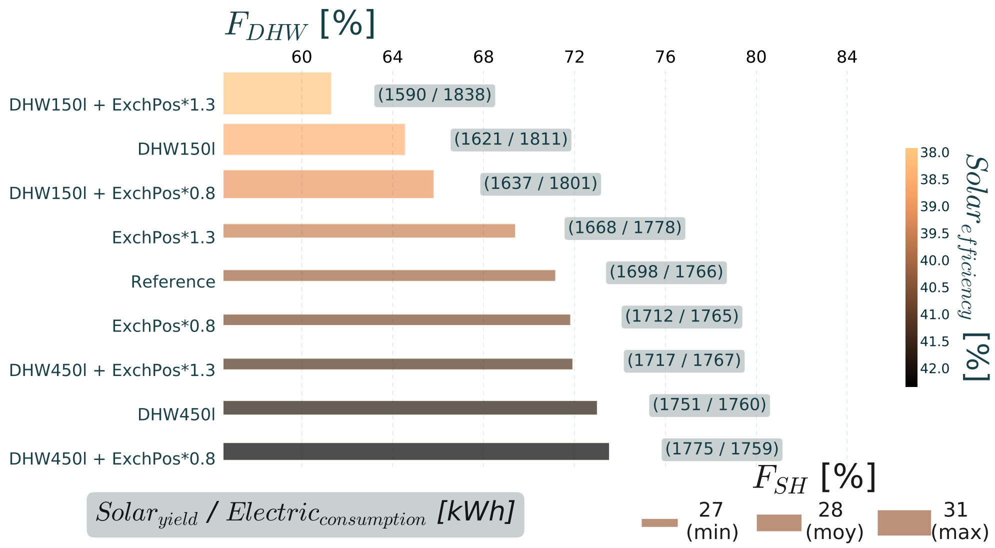


FIGURE 8 – *Impact of exchanger position inside the DHW tank on the SCS performance (01/10 to 30/04).*

## Conclusion

In this paper, we first presented a detailed model for $SCS$ components as well as an original control algorithm implemented in Dymola through Modelica language. In order to assess $SCS$ performance and get some insights on the way to size each component, a parametric study has been carried out.

Results showed solar combi-system coupled to NZEB can reach high performance with a simple yet effective controller. A cascade feed forward control algorithm was used, which account for solar losses and optimize energy flows. It dynamically adapts pumps speed to provide optimal conditions for collector effective operation. Coupled to a high level priority controller, solar energy is allocated efficiently even when multiple pumps are activated all at once.

$SCS$ was shown to perform well without nighly reduced temperature for both studied climates : Bordeaux and Strasbourg. Moreover, $SCS$ simulation results state that $DHW$ weekly-schedules do not change its performance but monthly demand variation does. Tank volume variation results pointed out an important impact when $F_{DHW}$ and $F_{SH}$ are analyzed separately, and the $DHW$ exchanger position must not be disregarded especially for unpropitious climates. Importance of panel orientation and tilt was also evaluated. Results showed South orientation must be a priority in conjunction with panel tilt higher than location latitude when possible.

With only $9.28\,\mathrm{m}^2$ the $SCS$ proved to be able to cover more than 66 % in an unpropitious climate as Strasbourg and more than 86 % for other cities of the total energy demands. Solar system in $NZEB$ may then be considered not only to provide $DHW$ but also as a way to cover $SH$. Lastly, Results also emphasized the importance of internal loads when $NZEB$ buildings are evaluated.

Three main indicators were identified in the aim to investigate $SCS$ improvement through an optimization process of system and house envelope : building and equipment cost, auxiliary consumption, $F_{SH}$, and $F_{DHW}$. Distinction between $F_{SH}$ and $F_{DHW}$ has been made as $F_{solar}$ only give partial information on $SCS$ response and auxiliary consumption is needed to evaluate performance regarding conventional systems. Furthermore, in order to meet the $NZEB$ energy balance requirement, roof area will be shared with $PV$ panels for on-site production. With main indicators identified, a sensitivity analysis will be performed on the model to select only most influent factors for the optimization process. Coupled to a new approach based on *Artificial Bee Colony* ($ABC$) currently developed, optimal solutions will be identified (Pareto front). This process will then allow a better understanding of solar systems potential for $NZEB$ households and may lead to improvements of existing systems in the market.

## Références


ADEME, C. (2016, July). Les besoins d'eau chaude sanitaire en habitat individuel et collectif.

Camacho, E., F. Rubio, M. Berenguel, and L. Valenzuela (2007). A survey on control schemes for distributed solar collector fields. Part II : Advanced control approaches. *Solar Energy 81*(10), 1252 – 1272.

CSTB (2011, August). Méthode de calcul Th-BCE 2012.

Cuadros, F., F. López Rodríguez, C. Segador, and A. Marcos (2007). A simple procedure to size active solar heating schemes for low-energy building design. *Energy and Buildings 39*(1), 96 – 104.

Duffie, J. and W. Beckman (1980, Jan). *Solar engineering of thermal processes.* John Wiley and Sons,New York, NY.

Eike Musall, Tobias Weiss, Karsten Voss, Aurélie Lenoir, Michael Donn, Shaan Cory, and François Garde (2010, March). Net Zero Energy Solar Buildings : An Overview and Analysis on Worldwide Building Projects. Technical report, IEA Task 40 - Net Zero Energy Solar Buildings - Subtask C : Advanced Building Design, Technologies and Engineering.

European Environment Agency (2012). Energy efficiency and energy consumption in the household sector.

EuropeanUnion (2010, May). DIRECTIVE 2010/31/EU on the energy performance of buildings (recast). Official Journal of the European Union.

Faezeh Mosallat, Tarek ELMekkawy, Daniel Lepp Friesen, Tom Molinski, Shaun Loney, and Eric L. Bibeau (2013). Modeling, Simulation and Control of Flat Panel Solar Collectors with Thermal Storage for Heating and Cooling Applications. *Procedia Computer Science 19*, 686 – 693.

Federal Ministry for Economic Affairs and Energy (2014). Overview of legislation governing Germany's energy supply system.

Ferhatbegovi, T., G. Zucker, and P. Palensky (2011, September). Model based predictive control for a solar-thermal system. In *AFRICON, 2011*, pp. 1–6.

Georgios Martinopoulos and Georgios Tsalikis (2014). Active solar heating systems for energy efficient buildings in Greece : A technical economic and environmental evaluation. *Energy and Buildings 68, Part A*, 130 – 137.

Georgios Tsalikis and Georgios Martinopoulos (2015). Solar energy systems potential for nearly net zero energy residential buildings. *Solar Energy 115*, 743 – 756.

Igor Sartori, Assunta Napolitano, Anna J. Marszal, Shanti Pless, Paul Torcellini, and Karsten Voss (2010, March). Criteria for Definition of Net Zero Energy Buildings. Technical report, IEA Task 40 - Net Zero Energy Solar Buildings - Subtask A : Definitions and Implications.

Jens Glembin, Mario Adam, Jörn Deidert, Kati Jagnow, Gunter Rockendorf, and Hans Peter Wirth (2012). Simulation and Evaluation of Different Boiler Implementations and Configurations in Solar Thermal Combi Systems. *Energy Procedia 30*, 601 – 610.

Karsten Voss, Eike Musall, and Markus Lichtme (2011). From Low-Energy to Net Zero-Energy Buildings : Status and Perspectives. *Journal of Green Building 6*(1), 46–57.

Kicsiny, R. and I. Farkas (2012). Improved differential control for solar heating systems. *Sol. Energy 86*(11), 3489 – 3498.

Laurent Reynier, Matthieu Cosnier, Jean-Christophe Visier, Charles Pele, and Danie Quenard (2014, June). Proposition d'indicateurs et d'un référentiel définissant la maison à énergie positive.

Lygouras, J., P. Botsaris, J. Vourvoulakis, and V. Kodogiannis (2007). Fuzzy logic controller implementation for a solar air-conditioning system. *Applied Energy 84*(12), 1305 – 1318.

Michael Wetter, Wangda Zuo, Thierry S. Nouidui, and Xiufeng Pang (2014). Modelica Buildings library. *Journal of Building Performance Simulation 7*(4), 253–270.

RDH, B. E. L. (2014, April). International Window Standards. Technical report, RDH, Building Engineering Ltd.

Singh, G., M. Zaheer uddin, and R. Patel (2000). Adaptive control of multivariable thermal processes in {HVAC} systems. *Energy Conversion and Management 41*(15), 1671 – 1685.

Task26 (2003, April). Report on Solar CombisCombi ModModel in Task 26 (System Description, Modelling, Sensitivity, Optimisation).

Yoann Raffenel, Enrico Fabrizio, Joseph Virgone, Eric Blanco, and Marco Filippi (2009). Integrated solar heating systems : From initial sizing procedure to dynamic simulation. *Solar Energy 83*(5), 657 – 663.

Éric Vorger (2014). *Étude de l'influence du comportement des occupants sur la performance énergétique des bâtiments.* phdthesis, École nationale supérieure des mines de Paris.