# Simulation results of high solar fraction combisystems in different European locations using TRANSOL 3

**Aristotelis Aidonis[1*]**, **Mario Motta [2]**, **Marco Calderoni[3]** , **Angel Carrera[4]**

[1,2] Politecnico di Milano-Dipartimento di Energia, via Lambruschini 4, 20156 Milan (MI), Italy

[3] SUNDAY progetti per l'energia S.r.l, Via Lepontina 12, 20159, Milano (MI), Italy

[4] AIGUASOL, C/ Roger de Llúria nº 29 3er-2a 08009 Barcelona, Spain

* Corresponding Author, mail: aristotelis.aidonis@polimi.it

**Abstract**

The current work presents and analyzes the results of simulations using the software TRANSOL 3[1] for high solar fraction combisystems in three different European locations. The main work aim is to examine the potential of high solar fraction configurations in energy and economy terms. Dimensioning criteria that result to sound economies are chosen and compared among typical small/medium residential buildings of three different locations in Greece, Italy and Germany. Simulation results (solar yields) and some economy aspects are presented under the selected dimensioning criteria. Solar fractions up to 50% are achieved. Additional prices in some cases of well insulated houses are lower than 60€ per $m^2$ of house living area. However, payback times often result high and the need for price reduction is evident. Moreover, some interesting characteristics of the simulation procedure are briefly described. Finally, an advanced combisystem configuration (in combination with a reversible sorption heat pump) is introduced as an issue for further analysis.

## 1. Introduction

EU objectives for 2020 are ambitious and need high investments in renewable energy technologies in every sector. Buildings account for about 40% of EU final energy consumption and represent therefore a crucial target. Since heat is a major part of such energy need, solar heating is a necessary technology to meet 2020's targets. Looking deeper at energy consumption of buildings, one will notice that, a part from the domestic hot water demand, a substantial amount of heat is required for space heating. For this reason solar combisystems[2] must play a major role in the future.

According to the newest building standards, which will get even stricter by 2020, high solar fraction solar combisystems are a concrete possibility. The present paper aims at showing feasibility of combisystems with solar fraction up to 50 %.

## 2. System description

### 2.1. User and system configuration

The building category of the two-family houses has been considered with a (reference) area of $200m^2$. A large amount of buildings belongs in this category in Italy [1] as well as in the other two countries

[1] Developed by AIGUASOL (www.aiguasol.com) and CSTB (www.cstb.fr)

[2] Combisystems: those system that, apart from domestic hot water, provide also space heating.

involved. Moreover, this building dimension is closed (in terms of energy behaviour) to both the single family houses and the small multifamily dwellings, thus allowing a reasonable extension of the results to an even larger range of buildings.

Figure 1 represents the plant configuration as seen in the desktop of TRANSOL 3 interface. It is a quite common configuration with the following main characteristics:

- Flat plate solar collectors (south oriented and with optimised inclination for each location).
- External heat exchange between the primary loop and the tank.
- Instantaneous production of sanitary water through a “quick” heat exchange device.

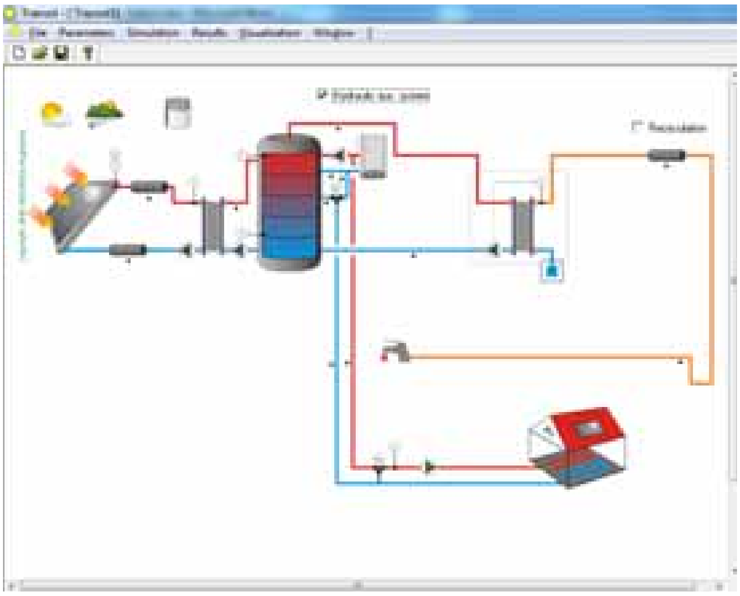

Figure 1: the plant configuration as seen in the desktop of TRANSOL 3 interface

**2.2. Definition of demands and dimensioning criteria**

Two categories of buildings have been taken into consideration:

A. Existing buildings, with a U wall value of 1,1 $W/m^2K$ and single windows of 6mm

B. Renovated (or new) buildings, with a U wall value of 0,3 $W/m^2K$ with double low-e windows “6/8/6” .

In all cases the surface of the windows is  assumed to be 15% of the walls’ surface.

The different locations are Athens, Genoa and Stuttgart, which have been chosen in order to cover a wide range of climatic conditions and thermal energy demands.  For the dimensioning of the solar thermal collectors the criteria used are following: the maximum collectors’ field area is equal to the 20% of the house area (thus 40$m^2$ of collectors  in our case). This limit has been chosen following the experts’ experience in order to avoid overdimensioned plants which result in poor energy yield per $m^2$ of collector and, thus, in poor economic performance.  If with this maximum collectors’ field area more than 50% of the total heat demand (for domestic hot water and space heating) is covered, then the collectors surface is reduced so that the overall solar fraction just reaches[3] 50%.

The tank volume in all plants is about 70 litres per $m^2$ of collector. For the tank simulation, TRANSOL 3 uses (for this combisystem configuration) type 340 of TRNSYS [2] with 12 nodes.

The temperatures used for the space heating distribution systems are the following: (delivery - return) 40 °C - 30 °C for the well insulated houses and 55 °C – 40 °C for the non well insulated houses.

## 3. Simulations and results

### 3.1. Energy results

The main results of the simulations with TRANSOL 3 are summarized in Tables 1 and 2 for U wall values of 0,3 and 1,1 $W/m^2K$ respectively. The results presented here are for a good quality flat plate collector ($\eta_o$=0,79, $a_1$=3,48 $W/m^2K$ $a_2$=0,0164 $W/m^2K^2$). The daily domestic hot water consumption is assumed equal to 420 l at 45°C.

| Location | $m^2$ of collectors | Fraction of collectors to house area | Gross demand (kWh) | Solar contribution (kWh) | Global solar fraction |
|---|---|---|---|---|---|
| Athens | 9,3 | 5% | 9610 | 4943 | 51% |
| Genoa | 14,0 | 7% | 10838 | 5206 | 48% |
| Stuttgart | 39,6 | 20% | 21345 | 8385 | 39% |

Table 1: simulation results with wall U value of 0,3 $W/m^2K$

| Location | m2 of collectors | Fraction of collectors to house area | Gross demand (kWh) | Solar contribution (kWh) | Global solar fraction |
|---|---|---|---|---|---|
| Athens | 25,6 | 13% | 20625 | 10037 | 49% |
| Genoa | 39,6 | 20% | 23584 | 10731 | 46% |
| Stuttgart | 39,6 | 20% | 44104 | 10238 | 23% |

Table 2: simulation results with wall U value of 1,1 $W/ m^2K$

### 3.2. Economic considerations

The idea behind the applied dimensioning criteria is to consider solar combisystems with sound economy. It is in fact interesting to refer to the additional price of the solar system per $m^2$ of the housing area. This is presented in table 3.

[3] Since the solar field is made of single collectors with a certain unitary surface (of about 2,33 $m^2$ in our case) the resulting solar fraction (using a discrete number of collectors) will never be exactly 50% but around this value.

| €/ $m^2$ of housing area | Case of well insulated house | Case of non well insulated house |
|---|---|---|
| Athens | 30 | 83 |
| Genoa | 60 | 168 |
| Stuttgart | 168 | 168 |

Table 3: price of solar combisystems per $m^2$ of the housing area

The assumptions for the system prices are the following: 650 €/ $m^2$ in Greece and 850 €/ $m^2$ in Italy and Germany (final plant prices, including installation and VAT).

Table 3 indicates clearly the advantage of the well insulated house in the economy of the solar combisystem, with the exception of Germany, where the high price per $m^2$ and the "difficulty" to achieve the same high solar fraction as in the other two countries indicates that the dimensioning criterion should be different. In fact, the annual solar energy yield of the German system (for the well insulated house) results to be particularly low (212 kWh/ $m^2$).

On the other hand, a "conventional" economy analysis approach would examine the solar plant as a "stand alone" investment considering its payback time. Under this aspect it results that only with substantial subsidies the payback times are lower than the lifetime of the plants. In particular, for the well insulated house, payback is 12 and 16 years for Athens and Genova, if we consider a subsidy percentage of 40% and 50% respectively.

The above results indicate that somehow the price of the combisystems should be reduced in order to be competitive in economy terms against conventional energy solutions[4]. Some ways to do so could be the standardisation of systems, more experience of installers (thus, less installation effort) and higher diffusion of the systems into the market.

## 4. Characteristics of the simulation procedure

Some of the simulation procedure characteristics that are worth mentioning in TRANSOL 3 are the following:

- It "incorporates" design experience on solar engineering. This has affected the parameters of the TRNSYS models and that are used behind the user friendly interface but has also permitted a series of "smart" (dynamic) default values for the various components of the solar plant. For example, once the user defines the solar collectors area, the program sets reasonable values for most of the components characteristics as tank volume, primary and secondary circuit pipe diameters, heat exchangers and pumps parameters etc.

[4] The payback time reported here is a result of the economic analysis of TRANSOL, using the following values: inflation rate for the energy prices 4%, general inflation rate 2% and natural gas prices 0,48€/$m^3$, 0,76€/$m^3$ and 0,68€/$m^3$ for Greece, Italy and Germany respectively.

- Simulation time is short, usually less than 1 minute for a combisystem. This is done thanks to the optimised combination of TRNSYS models.
- Parametric runs are possible, thus offering the possibility to optimize collector's type, inclination, tank volume etc.
- Apart from the usual solar plant configurations (single family, apartments block and collective building) there are new specific configurations of solar thermal plants for industrial processing and for solar cooling.

## 5. Further analysis – the "high combi" configuration

Obviously, the combination if solar heating with solar cooling is advantageous in energy terms (for climates where a cooling demand exists), since it allows the use of the "excess" solar heat in summer period. In this paragraph a specific configuration of solar heating and cooling that allows higher solar (or renewable) fractions is qualitatively presented .

The name "high-combi" refers to an FP6 EU project (http://www.highcombi.eu/) which aims at developing high solar fraction systems by an innovative combination of optimized solar heating, cooling and storage technologies [3]. Within this project, some research and demonstration activities are focused on the combination of a solar heating and cooling system with a reversible sorption heat pump. It is worth mentioning that nowadays the use of heat pumps (most of them conventional) together with solar systems is a starting to be a common market tendency for many solar companies.

Combining the solar system with a reversible ad-absorption heat pump may offer the possibility to increase further more the renewable energy fraction and, in some configurations, to approach or even reach 100%.

One configuration is represented in figure 2. Apart from the usual components of a solar heating and cooling system, this configuration has the following particularities:

The thermal (solar) tank is buried, thus it is a medium or long term thermal storage[5]

Geothermal heat exchangers are positioned in the surroundings of the solar tank.

A biomass burner (which could be a fireplace with heat recovery) is used as auxiliary heating source.

[5] The buried storage capacity to be kept worm with time depends on many parameters, the first being its volume (actually its surface to volume ratio), its insulation etc. If big and insulated enough, it can be seasonal, i.e. it can practically store heat from summer to winter.

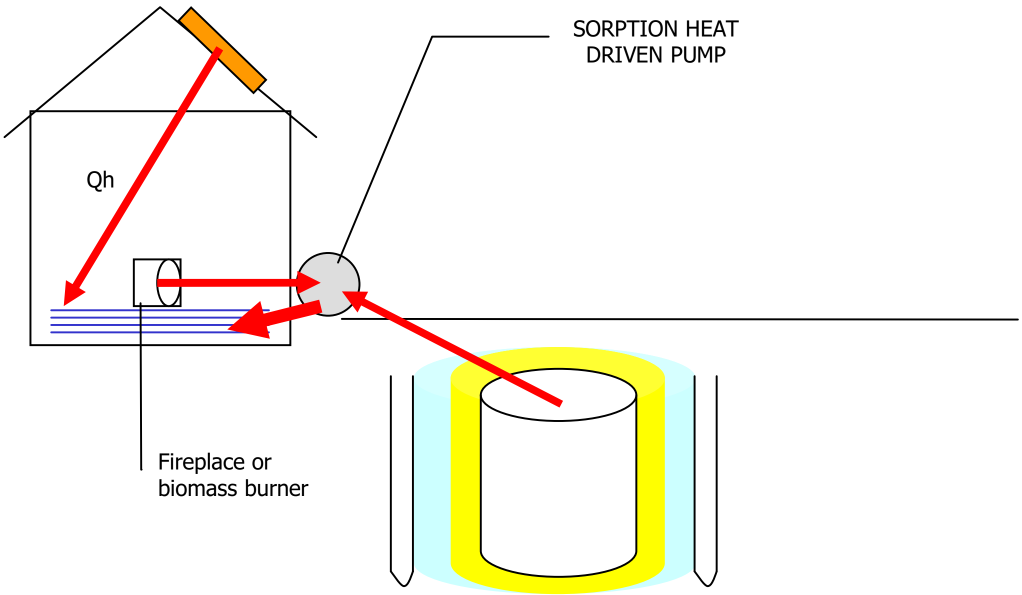


Figure 2: schematic presentation of the winter operation mode of a "High Combi type" plant

Figure 2 represents the winter operation of the plant (thus, with space heating demand). When the solar collectors reach a minimum temperature level (e.g. $40^o$ C) they deliver heat directly into the building. When they don't, then one of the following may occur:

- The thermal tank delivers heat to the building (if its temperature is high enough).
- The biomass burner, drives the sorption heat pump which "pumps" thermal energy from the tank into the building.

The advantage in this second operation mode (if compared with other "non solar" solutions) is that there may be still an option for the solar collectors to operate with particularly low temperatures (since the tank has a temperature of less than $40^o$ C and it is further cooled down by the heat pump) and for the sorption heat pump to operate with a high "Cop" (since the cold source – the thermal tank – has a much higher temperature than the ambient air, or even the earth, in winter).

During summer, one of the following may occur:

- The collectors drive the sorption heat pump (operating now as a chiller) directly to cool the building.
- The collectors heat up the storage when there is available solar radiation but no cooling load.
- The heat storage (if its temperature is high enough) is driving the sorption chiller when there is cooling load but no available solar radiation.

When the chiller is operating, the rejected heat is partially or completely delivered to the earth through the geothermal heat exchangers that are surrounding the tank. This fact, if correctly dimensioned, may offer a thermal "shield" to the tank.

The above is referred to the cooling load only, since during summer the domestic hot water consumption is easily covered by the solar energy, either directly or not.

During spring and autumn (when the only load is for domestic hot water) there is usually some excess of solar energy produced which is stored in the tank.

A similar but simpler configuration (without any buried component) is possible and may be already applicable at a market level[6].

## 6. Conclusions

Solar combisystems are a mature technology and a technically valid solution that can offer substantial solar fractions in different European climates.

Their cost for the final user, if referred to the house living area is in most cases low and affordable. However, if seen as a stand alone investment, the "conventional" economic analysis often results in high payback times even when substantial subsidies are applied. Thus, any possible effort should be applied in order to reduce the market price. Moreover, advanced solar technologies with improved energy and economy performance should be further promoted.

TRANSOL 3 has been proved to be a practical and powerful software for combisystems simulation.

Further applied research is needed for advanced solar plants configurations, like the combination with the sorption heat pump described in this paper.

## References

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[6] A similar simplified configuration (with some variations) will actually be adopted in the demonstration plant of the High-Combi EU project in Italy.