EuroSun 2010 – Concentrated Heat Storage for Solar Heating

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Abstract

The FP7 sponsored DEARSUN project (short for 'DEvelopment of a direct solAR heating System capable of covering a full-year thermal load UsiNg high temperature thermal storage') was initiated in 2008 to develop a solar thermal heating system capable of covering the full-year heat and hot water load of a single family house using high temperature thermal storage. ACE Group with a team of European solar thermal experts, research institutions and industrial partners designed and optimized the system combining off-the shelf and innovative components (heat transfer fluid, highly insulated storage tanks, control system) with the aim of creating an efficient, affordable and reliable solar thermal solution operating at high temperature for small and medium sized buildings. In 2009, the first prototype system was produced and installed on a pilot home. Actual performance of the prototype system over the 2009-2010 heating period has been closely monitored using web applications and evaluated against simulations and system performance expectations demonstrating the promising potential of this renewable energy solution for homes in south and central Europe.

1. Introduction

The energy demand in residential buildings amounts to approximately 30% of the overall energy demand in Central Europe, the share of hot water and space heating being about 12% and 75% respectively. In times of an ever-increasing energy demand and the peak of gas and oil extraction to be reached in the near future, energy from renewable energy sources is one way of securing the world economy's energy demand while at the same time contributing to climate protection. Solar combi-systems with a market share of more than 50% in the solar sector already in 2008, are gaining in significance. The aim of the Solar Thermal Vision 2030 (ESTTP) has been defined to cover low-temperature heat needs for heating and cooling in the residential sector by solar active housing by 100% and 50% in refurbishments which shall be achieved by improved technological approaches and reduced heating demand in modern buildings. At present even in the sunniest regions of Europe, solar heating systems for small buildings are not yet capable of supplying the full year energy supply by exploiting solar radiation. Existing solar installations for private homes are typically sized to prevent excessive heat build-up in summer when demand is low, and as a result are incapable of exploiting the much lower winter solar gains for heating or even hot water needs. The DEARSUN project set a goal of developing an innovative high-temperature solar heating system able to generate the thermal load for a single building covering the heat demand year round without curtailing living comfort conditions as a contribution to an effective use of renewable energies.

2. DEARSUN system design and development

The purpose of the DEARSUN research project was to validate the design of an autonomous solar heating system at a scale close to industrial applications and compatible with the SME financial capabilities. It is based on the French patent application N°07/011820, whereby standard solar panels are connected to highly-insulated storage tanks containing high-temperature thermodynamic fluid.

2.1. System components

High-efficiency vacuum-tube solar collectors are used to deliver heat to the storage tanks via an innovative heat transfer fluid, also being used as storage medium in the storage tanks. The heat transfer fluid, a mono propylene glycol, is capable of withstanding operating temperatures higher than 160°C. Two types of storage tanks are used: domestic hot water tanks operating at temperatures between 15° and 90°C and high temperature storage tanks with a capacity of 300 liters designed to store heat for several months at temperatures between 50° and 150°C.

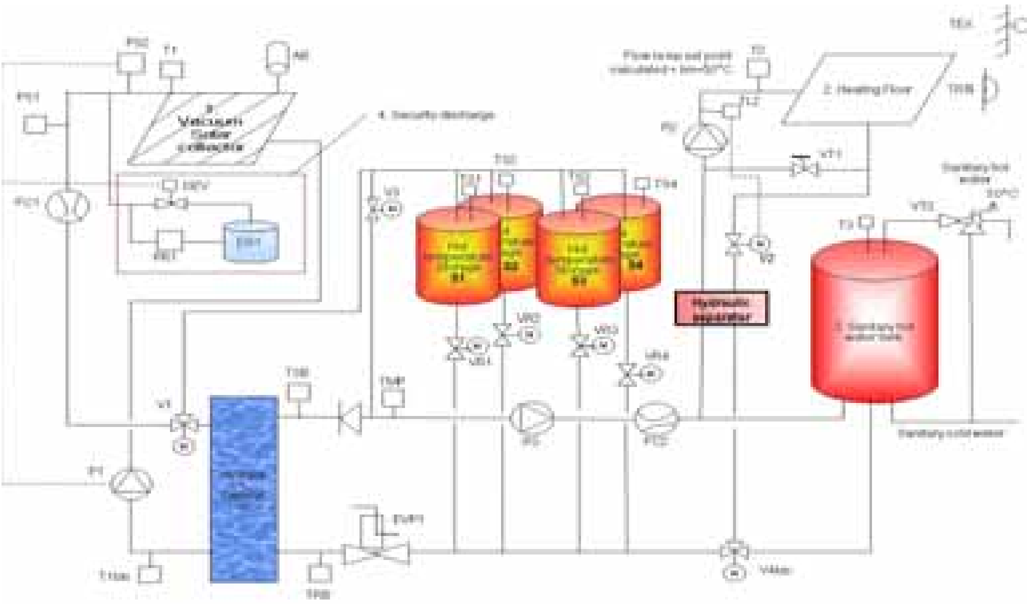

Fig. 1. The DEARSUN system

With the exception of the control unit and the high temperature storage tanks, the system utilizes technologies and components already available on the market.

2.2. Simulations

The conceptual design and hydraulic scheme were initially verified by simulation taking into consideration fixed and variable parameters (such as site, area of solar collectors, angle, volume of tanks, flow rates). Simulations were performed for a standard single family house with 5 rooms, an area of 100 m^2, equipped with a radiant floor heating. In order to analyze the requirements and costs of the application of the DEARSUN system in a variety of potential markets, simulations were performed for 5 different locations in South and Central Europe, with building thermal characteristics adapted to national building energy codes (cf. Table 1).

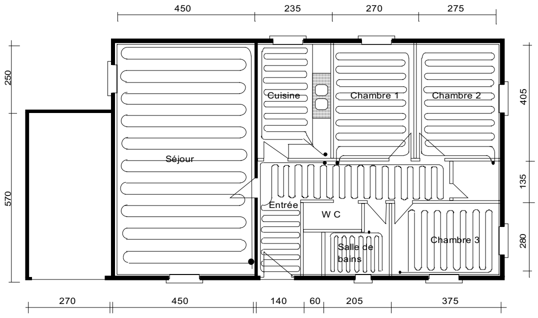

Fig. 2. Floor plan - Simulation case study

	Space heating demand (kWh/m².y)	DHW demand (kWh/m².y)
Nice	18.2	10.4
Zurich	54.8	12.3
Roma	20.6	10.4
Vienna	39.5	12.3
Constanta	31.6	10.4

Table 1. Annual building energy demand

Simulations were performed with the dynamic simulation tool TRNSYS and designed to simulate the performance of thermal energy systems by calculating the performance of the DEARSUN components over the period of one year and generating hourly data.

2.2.1. Results

Considering a solar system operating at high temperatures, the simulation included the assessment of the temperature levels approached during operation. Calculations for the reference case in a Mediterranean climate demonstrated that the liquid at the solar collector outlet reaches a maximum of about 160°C, whereas the temperature does not exceed 120°C when the solar pump is in operation. To prevent overheating of the system the solar pump empties the collectors as soon as the storage tank temperature reaches 150°C. The innovative controlling units in combination with the pumps make sure that the unique charging/discharging process is optimized by directing the heat transfer fluid from the solar collector to the storage tank with an upper temperature closest to its own, allowing for tanks at different temperature levels. Discharging was regulated in such a way that a tank with cooler liquid is tapped until its temperature is lower than that required.

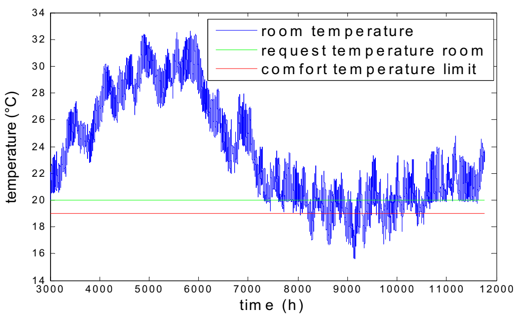

Fig. 3. Indoor air temperature over the year without auxiliary heating – Nice

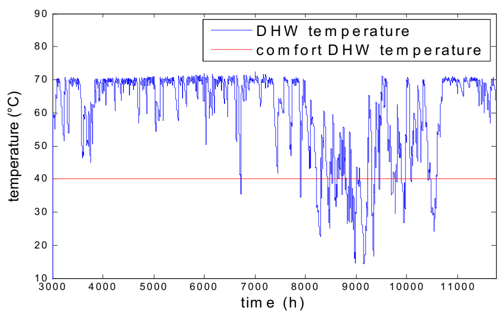

Fig. 4. Upper temperature of DHW over the year without auxiliary heating – Nice

The reference case represented a single family house in a Mediterranean climate (Nice). Initial simulations (solar collectors with an area of 15m^2 and a storage capacity of 900l in 3 tanks of 300l each connected in series) were carried out without any additional energy source, showing that thermal comfort needs (room temperature permanently over 19°C, DHW upper temperature constantly over 40°C) could be achieved during 90% of the year. Since indoor air temperature dropped below 19°C during 700 hours (8%) of the year and DHW temperature below 40°C during 440 non-consecutive hours (5%), a back-up system would be needed to guarantee the thermal comfort conditions. For this reason, in the later pilot installation, an electric auxiliary heating system was installed in the DHW tank, and a gas boiler integrated into the system to support space heating when solar energy supply is not sufficient.

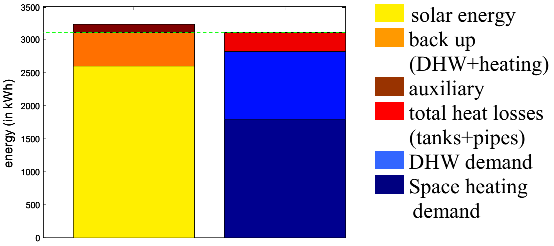

Fig. 5. Annual energy balance – Nice
(15m² solar collectors, 900l tanks)

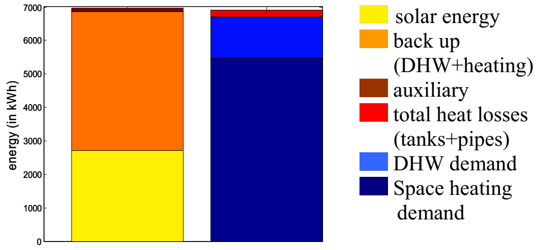

Fig. 6. Annual energy balance – Zurich
(20m² solar collector, 1200l storage tanks)

Results from simulation runs for a Central European climate (Zurich) reflect space heating demand 3 times higher. Here the energy provided by the DEARSUN solar system covers 43% of the energy needed for thermal comfort conditions. Considering additional energy needed for pumps, the energy saving potential of the DEARSUN system is Fsav,ext=75% for the Mediterranean climate and Fsav,ext=39% for the Central European climate case.

	F_{sav}(-)		Primary energy consumption[1] (kWh/m²)	CO_2 avoided[2] (kg)
	thermal	**extended**		
Nice (15m², 900l)	0.84	0.75	11.8	559
Zurich (20m², 1200l)	0.43	0.39	44.0	556
Roma (15m², 900l)	0.77	0.69	14.6	561
Vienna (20m², 1200l)	0.42	0.38	43.0	510
Constanta(20m², 1200l)	0.56	0.51	29.7	576

[1] Space heating + DHW + auxiliary system (pumps)
[2] Conversion factor: 180 g CO_2/kWh for electricity and 206 g CO2 /kWh for gas

Table 2. Annual energy performances for different European climates

2.3. Prototype development

Simulation results served as basis for the final design and manufacturing of the prototype storage tanks. The tanks use a combination of arc welding and laser welding and are packed in layers of high-efficiency insulation and aluminium sheets. Four prototypes were manufactured in Spain and reliability tests performed between January and August 2009 at a demonstration site in Rians, France.

2.4. Pilot installation

In winter 2009, the prototype system was assembled on a country house in Rians in Southern France. This building consists of one principal room on one floor with an area of 120m^2 and a height of 3,25m^2. The main orientation being south corresponds to the characteristics of the reference building assumed in the simulation runs, just like its being equipped with a heating floor operating at low temperature.

Building elements	Roof	Floor	Wall to outside	Window
U-value (W/m².K)	0.38	0.64	1.88	2.95/1.31

Table 3. U-values for Rians building

Space for the technical equipment is provided in an extra room ($5m^2$) at the back of the building. The principal room is in use every day, the daily volume of domestic hot water is about 80 liters per day corresponding to the demand of 2 people.

2.5. Field test

In February 2010 the monitoring period of the DEARSUN system started. Six direct flow vacuum tube collectors were connected in series totaling an area of $17m^2$. Mounted on a trailer outside the building, the solar collectors were connected to 4 storage tanks with a capacity of 300 liters each placed at a distance of 10 metres in the technical room. The heat is transferred by the mono propylene glycol circulating in the solar collectors and the storage tank, in the heat exchanger and connection pipes, and used for the generation of domestic hot water.

Fig. 7. Rians testing site

Fig. 8. Floor plan

Fig. 9. Rians main room

In order to meet the requirements of the inner temperature reaching up to 160ºC and the outside contact temperature of less than 40ºC and limitations of space, a special insulation strategy had to be developed. The insulation of the cylindrical storage tanks of stainless steel is unique in that the shell consists of two layers of Spaceloft by Aspen Aerogel with high thermal resistance at high temperatures separated by an airgap and covered by a layer of Polyisocyanurate with high thermal resistance at medium–low temperatures.

Fig. 10. Storage tank

2.5.1. Results

While an analysis of the data for the outlet temperature of the solar collectors (cf. Fig. 11) confirms the results of the simulations, the performance of the tanks in the Rians house reveals discrepancies between the collected data in the field test and calculations in the simulation runs. Contrary to the original assumption that it would take approximately 20 days until the temperature of the glycol would fall from 150°C to 40°C, thermal losses are higher than expected, showing the need to readjust simulation parameters by a heat loss capacity rate.

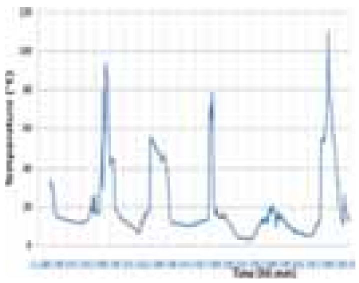

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Fig. 11. Outlet collector temperature

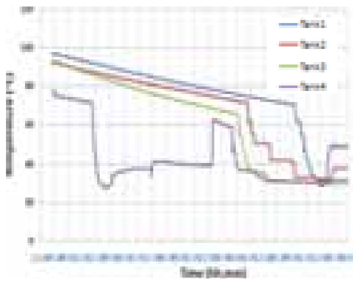

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Fig. 12. Storage tank temperature

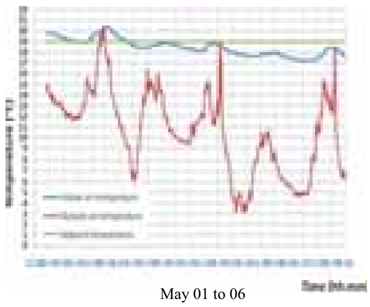

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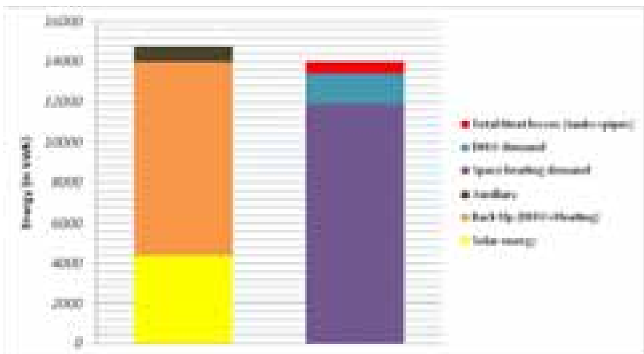
Fig. 13. Indoor and outdoor temperature

Discrepancies between the reference building and the field test with regard to the heat transfer fluid and the capacity of the space heating demand result from the fact that the Rians house is an old building with low thermal insulation and high energy demand for space heating.

	Space heating demand (kWh/m².year)	**DHW demand (kWh/m².year)**
Puits de Rians	100	13
Standard house	60	13
Low energy house	30	13
Passive house	15	13

Table 4. Rians space heating demand

The installation of the DEARSUN system on the building in Rians showed that a solar energy saving fraction of 28% can be achieved which corresponds to an annual energy saving of 4384 kWh equalling 1062 kg CO_2 emissions avoided.



$F_{sav, thermal} = 28\ \%$
$F_{sav, extended} = 10\%$

Fig. 14. Annual energy balance in Rians with solar collector area of 17 m² and 1200 l storage tanks

3. Conclusion

The DEARSUN system serves as a model for a compact solution which can help advance the solar thermal market share in Europe. Except for the innovative storage tank and the controller unit, there is no need to develop specific components since standard technologies are available off the shelf.

The installation of the system in a building in Southern France shows that all components of the DEARSUN system can withstand the high operating temperatures – temperatures rarely exceeding 120°C. While simulations had been carried out for buildings with average energy demand for space heating, the results from the field test reflect the Rians building's higher space heating demand as its values are representative of an old poorly insulated building. The solar energy saving fraction achieved amounts to 28% and when the system is extended to consider electricity needed for controller and pumps the rate is 16%. While real-time data of the outlet temperature of the solar collectors confirms the results of the simulations, the performance of the tanks in the Rians house reveals the need for further research since thermal losses are higher than calculated. In addition, attention will have to be paid to the optimization of the interaction of the single components (solar collectors, pumps, storage tanks), as well as to the sizing of the equipment (pumps, valves). The problem of high viscosity of the heat transfer fluid needs to be addressed with special consideration of the heat exchanger and the pumps.

By optimizing this high performance solar heating system and adapting it for buildings with low energy demand, the DEARSUN system can make an important contribution as Europe strives to meet renewable energy targets.

References

[1] D. BLANDIN, G. KRAUSS, H. BOUIA, P. RIEDERER, D. CACCAVELLI. A zonal approach for modeling stratified solar tanks.