STORAGE CONCEPTS FOR SOLAR DISTRICT HEATING AND COOLING SYSTEMS

Jesús López-Villada, Joan Carles Bruno, Alberto Coronas

Rovira i Virgili University, A. Països Catalans, 26, 43007, Tarragona, Spain

Corresponding author: jesus.lopez@urv.cat

1. Introduction

In Europe, the building sector is responsible for 40% of the primary energy consumption. Most of the energy is thermal energy consumed for heating, cooling and hot water preparation and comes directly or indirectly from the use of fossil fuels as oil, natural gas and coal. As is it known, these energy sources have two important problems: scarcity in the next years, which would increase the economic costs, and the generation of CO_2 emissions to the atmosphere that are directly related with global warming and climate change. Rosen (2009) demonstrates that non-fossil fuel energy options are needed to help combat climate change and today some renewable energy technologies are a good and economical competitive alternative to the traditional ones. As a consequence of all the facts mentioned above, the governments are approving new regulations to reduce the use of fossil fuels by energy efficiency and by the use of renewable energy sources as solar energy.

Solar energy is an abundant energy source and it is available in large or less extent everywhere. This is why it is interesting to use this energy source to cover all or part of the thermal energy needs of buildings. In addition, district heating and cooling networks allow the integration of waste heat, more energy-efficient equipment and renewable energy sources as solar thermal energy. These systems could reduce dramatically the investment and operational costs due to reasons of economics of scale. Usually solar district heating systems have a short-term heat storage and large-scale collectors. These systems are designed to cover practically most of the energy consumption in summer for the preparation of domestic hot water (DHW). Even so, in North and Central Europe (Bauer et al., 2009; Schmidt et al., 2003; Nordell and Hellström, 2000) we can find some pilot projects with seasonal thermal energy storage. The main objective of the seasonal storage is to store solar energy heat from the summer to the winter for space heating and DHW. We can find several methods for seasonal storage of solar thermal energy (Pinel et al., 2011) but most of the past and present systems store heat in sensible form using water, rocks and soil as storage mediums.

On the other hand, air-conditioning for buildings has become an important comfort demand of the building users during the last few decades in developed countries. As most of the air-conditioning systems are based on electrically driven compression units, the electricity consumption has increased dramatically, especially in the warmer periods of the year. In addition, usually an important proportion of this electricity is generated in central power stations that commonly burn fossil fuels. Then, one way to reduce the consumption of fossil fuels is the use of solar energy for cooling. According to Balaras et al (2007), the most energy-efficient and cost-effective solar cooling systems among all the technologies available are the ones based on solar thermal collectors and thermal chillers. Usually these systems are designed in a small scale for detached houses or buildings, presenting higher investment costs than the conventional systems based on compression units. Rezaie and Rosen (2011) point out that using low-temperature from renewable energy sources such as solar in district heating has proven to be attractive, reliable and with low maintenance. Then one way to reduce dramatically these costs is the integration of large solar cooling systems in district heating and cooling networks (DHC). The cost savings obtained is primarily due to the reduction of the initial investment for reasons of economy of scale of the equipment and the reduced operating costs due to higher thermal efficiency of large chillers.

Although solar district heating and cooling systems (SDHC) are not very common at present (Dalenbäck, 2007) they are of particular interest at places where the cooling demand is very important. Due to the heat consumption for cooling generation, it is evident that the thermal storage dimensioning would depend strongly on the ratio between the annual heating and cooling demands. Also it is important to consider that the typical demands profiles present low heating and cooling demands in the transition months during the spring and autumns seasons. That means that at least the thermal storage should be able to store the excess heat of the solar thermal systems in these periods of the year. Then, in this paper we analyse the dimensioning of the volume and solar collector areas for SDHC systems for several typical heating and cooling demand profiles for residential buildings and different meteorological sites. In this analysis, we compare the different cases using some annual factors as the solar fraction, the specific solar gains and the specific solar heating and cooling production.

2. Methodology

The size of the seasonal storage and the solar thermal plant of the SDHC systems depend mostly on three main factors: the thermal energy load of the buildings, the characteristics and operation parameters of the solar thermal field and the seasonal storage design. All of them are strongly influenced by the meteorology of the place where the SDHC system is located. Then, to establish some design guidelines of SDHC systems, it is necessary to analyse several case studies considering all these factors. For that reason in this work we have considered four Spanish cities with different weather patterns:

- Avila, with relatively very cold and long winters and short very hot summers.
- Barcelona, with mild winters and humid hot summers.
- Madrid, with cold winters and long hot summers.
- Sevilla, with very mild winters and very long hot summers.

Once the location is known and also considering the building factors described in tables 1 and 2, we can estimate the load hourly profiles of DHW consumption, heating and cooling. The DHW profile is estimated from the correspondent specific energy demand and the annual variation of the temperature of the tap water found at the standard UNE-EN 94002:2005 (AENOR, 2005). The hourly energy load profiles for heating, cooling consumption are estimated using the normalization of the annual energy demand with the degree-day values with and the variable base temperature approach (López-Villada, 2010; CIBSE, 2006). In this case, to determine the heating and cooling degree-day, it is considered that the base or reference temperature depends on the basic characteristics of buildings and does not take the typical value of 15 or 18 º C for heating and 21 ºC for cooling. Thus, from the specific energy demand, meteorological data and other basic data from the buildings, it is possible to determine the specific values of the annual base temperatures for heating and cooling.

Also, dealing with the SDHC system, we have compared the flat plate collector (FPC) and evacuated tube collector (ETC) technologies and considered a buried seasonal storage that uses water as storage medium (see fig. 1). Table 3 shows the main parameters of the FPC and ETC collectors considered and in table 4 you could see the main characteristics of the seasonal storage. It is assumed that part of the heat is produced by the solar system and the rest by a conventional boiler. In the same way, part of the cooling is produced by a single effect LiBr absorption chiller with a nominal cooling capacity of the 67% of the cooling peak demand. When the cooling exceeds this power or the temperature on the top of the seasonal storage is not high enough to activate the absorption chiller, it is assumed part the cooling load is produced by a centrifugal compression chiller.

Tab. 1: Main construction characteristics of the residential apartment buildings considered for the determination of heating, DHW and cooling energy hourly profile.

Number of dwellings	1000
Flat floor space (m^2)	100
Average storey height (m)	2.5
Building storey number	5
Volume / surface ratio	1.0

Tab. 2: Residential building energy parameters for the four cities analysed according to the Spanish construction and energy certification regulations. The overall heat transfer coefficients are extracted from the Technical Building Code of Spain (CTE, 2009) and the specific energy demands from the Spanish certification energy regulations (IDAE, 2009) for residential apartment buildings.

Building energy parameter		**City**			
		Avila	**Barcelona**	**Madrid**	**Sevilla**
Overall heat transfer coefficient **(W m^{-2} K^{-1})**	External wall	0.57	0.73	0.66	0.82
	Roof	0.35	0.41	0.38	0.45
	Floor in contact with soil	0.48	0.5	0.49	0.52
	Windows	2.6	2.9	2.5	3.3
Annual specific energy demand **(kWh m^{-2} y^{-1})**	Heating	69.5	28.3	43.2	16.6
	DHW	13.7	8.0	13.0	12.3
	Cooling	0.0	12.8	10.8	23.4

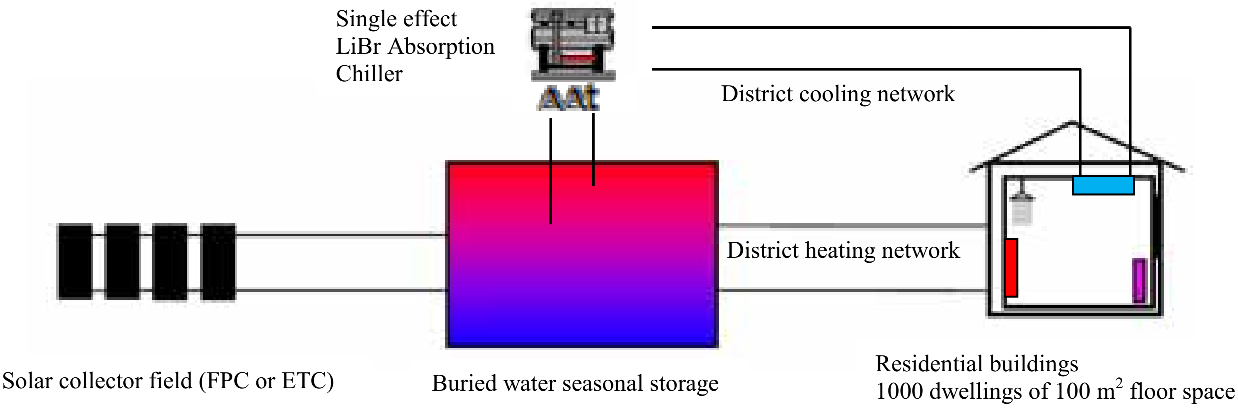

Fig. 1: Schematic diagram with the main components of the SDHC system.

Tab. 3: Main FPC and ETC solar collectors' parameters of the SDHC system.

	Flat plate collector (FPC)	**Evacuated tube collector (ETC)**
Intercept efficiency	0.69	0.798
Efficiency slope (W m^{-2} K^{-1})	2.61	0.9937
Efficiency curvature (W m^{-2} K^{-2})	0.0098	0.0097
Tested flow rate (kg h^{-1} m^{-2})	50	37.5

Tab. 4: Main seasonal storage parameters of the SDHC system.

Parameter	Value
Ratio height / diameter	0.5
Depth of the top in the ground (m)	1.0
Wall material and thickness (m)	Concrete, 0.25
Isolation thickness (m)	0.25
Thermal conductivity of the isolation (W m^{-1} K^{-1})	0.04
Average global heat transfer coefficient (W m^{-2} K^{-1})	0.15

Once we know the energy demand profiles, the characteristics of the solar thermal field and the different locations, we are able to calculate the energy performance of the SDHC systems with FPC and ETC solar collectors using the thermal systems simulation software TRNSYS 16 (2004). This software has an extensive library of thermal components as solar thermal collectors, boilers, storage tanks, pumps, thermal chillers, etc. We developed a specific model (type 811) to predict the energy performance of thermal chillers based on some linear correlations obtained by multivariable regression of the cooling capacity and heat consumption as a function of the temperatures of the external fluids (López-Villada, 2010; Puig-Arnavat et al., 2010). This method is an improvement of the method based on the characteristic equation temperature developed by Ziegler (1999). Also we used the multiport tank type 534 for the simulation of the seasonal storage tank and type 707 to model the thermal interaction between a buried vertical cylindrical storage tank and the soil. Ochs (2010) demonstrated that the use of this model among others is sufficient to determine the system energy balances and parameters such as storage volume in relation to collector area in transient system simulations for certain boundary conditions and load profiles.

Finally it is very important to optimize the SDHC in order to achieve the lower economical cost of the energy consumed. The optimization is performed with the TRNSYS application TRNOPT, that uses the optimization software GenOpt® developed by the Lawrence Berkeley National Laboratory (Wetter, 2009). The global cost of the SDHC system is evaluated according to the procedure described in the European standard UNE-EN 15459:2008 (AENOR, 2008), which is specific for the economic evaluation for the energy systems in buildings. We considered that, as we are dealing with large scale solar thermal systems, the total specific cost of the solar field is 400 € m^{-2} for the FPC and 650 € m^{-2} for the ETC (Peuser, 2002). Also the specific cost of the seasonal storage ranges from 100 € m^{-3} for volumes around 20000 m^3 and 500 € m^{-3} for volumes around 500 m^3, according to some practical experiences in Germany (Schmidt at al., 2003). For the global energy costs of the SDHC system it is assumed a period of 25 years, values of 3% and 4% for the general inflation and energy inflation respectively (FUNCAS, 2011), a financial interest of 4% (Boermans et al, 2011) and that natural gas is used as auxiliary energy with a specific cost of 35 € MWh^{-1} (CNE, 2011). It should be noted that at the end of the period of 25 years it has be considered that the seasonal storage has still an important residual value around a 50% of the initial investment, that is, that for the calculation of the solar and energy specific costs the considered cost for the storage is around a 50% of the investment.

3. Results and discussion

All the simulations performed have been optimised considering a slope of the solar collectors of 40º, a flow temperature of the district heating of 60 ºC and a flow temperature of 15 ºC for the district cooling. That means that the apartments use high efficient terminal elements for heating and cooling as low temperature radiators and high temperature fan-coils.

Fig. 2 to 6 show the energy demand patterns obtained for the four locations considered. It could be observed that the residential buildings in Avila present the highest heating demand and have no cooling demand in summer. Also buildings in Sevilla have the highest cooling demand in summer and the lowest heating load in winter. The heating and cooling loads for Barcelona and Madrid have similar patterns but in the case of Madrid the loads are approximately a 30-35 % higher due to the relatively more severe weather.

The results of the optimization of the SDHC systems for FPC and ETC collector technology and the different places are shown from table 5 to 12. When comparing FPC and ETC technologies, SDHC systems with ETC have always lower specific costs. As expected, the solar surface of the ETC collectors for the different seasonal storages volumes considered is lower than the correspondent area of FPC collectors, ranging from 2000 to 4500 m^2 in the first case and from 3000 to 6000 m^2 in the second case. The volume of the seasonal storage ranges from 10000 m^3 to 500 m^3. That means that the storage cost is between a 5% of the total investment for volumes around 500 m^3 and a 20% for volumes around 10000 m^3. The results show clearly that the higher the volume of the seasonal storage the higher the specific cost although the differences do not exceed the 20%. However, higher volumes mean also much higher solar fractions for heating and cooling.

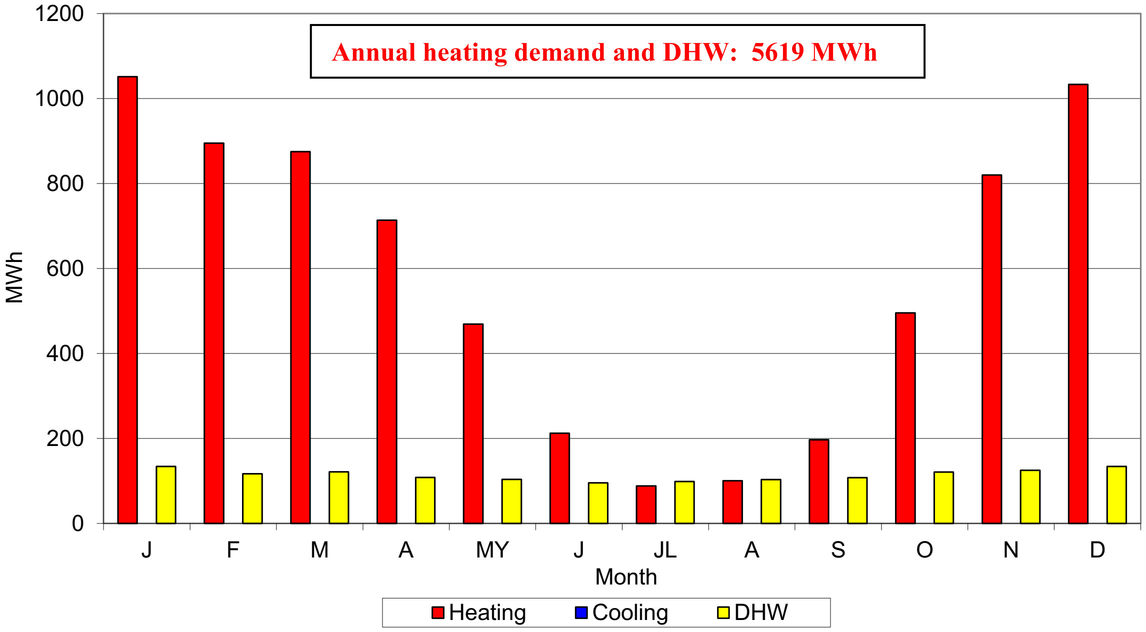

Fig. 2: Heating and DHW monthly demands for the 1000 residential dwellings in Avila.

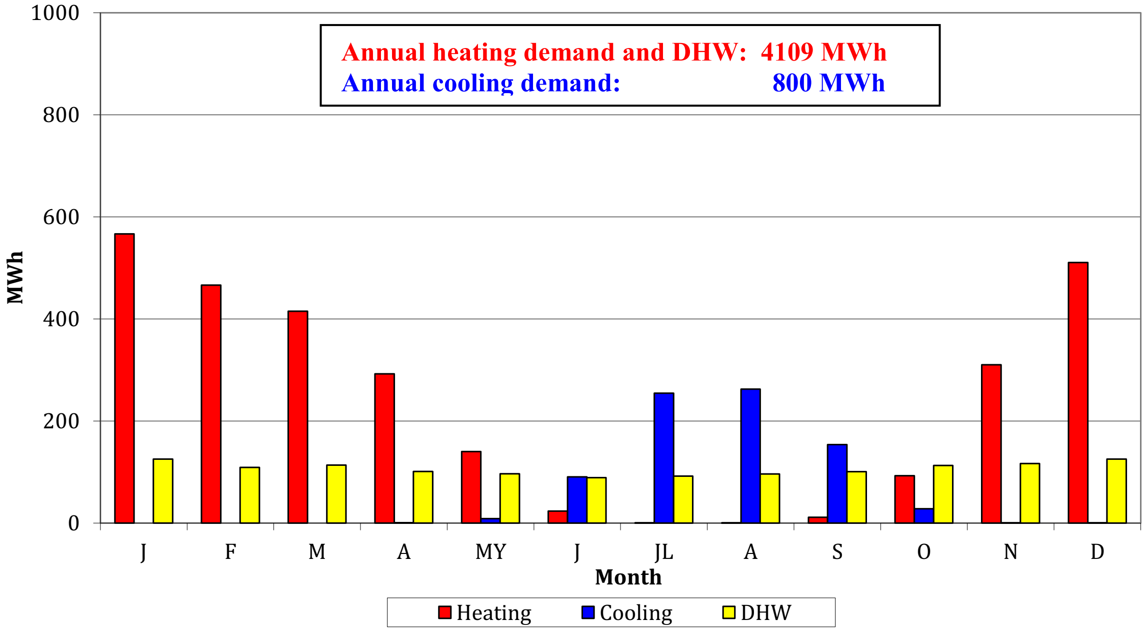

Fig. 3: Heating, cooling and DHW monthly demands for the 1000 residential dwellings in Barcelona.

One important aspect to notice is that, with the exception of some cases with larger volumes, the energy specific costs are lower than those for the conventional energy source (35 € MWh^{-1}). That demonstrates that SDHC systems could be economically competitive with conventional systems based on the use of fossil fuels. When comparing the different locations, Sevilla shows the lowest energy specific costs because of its higher values of the solar irradiation and the low heating load, being Barcelona and Avila the cities with the higher specific costs.

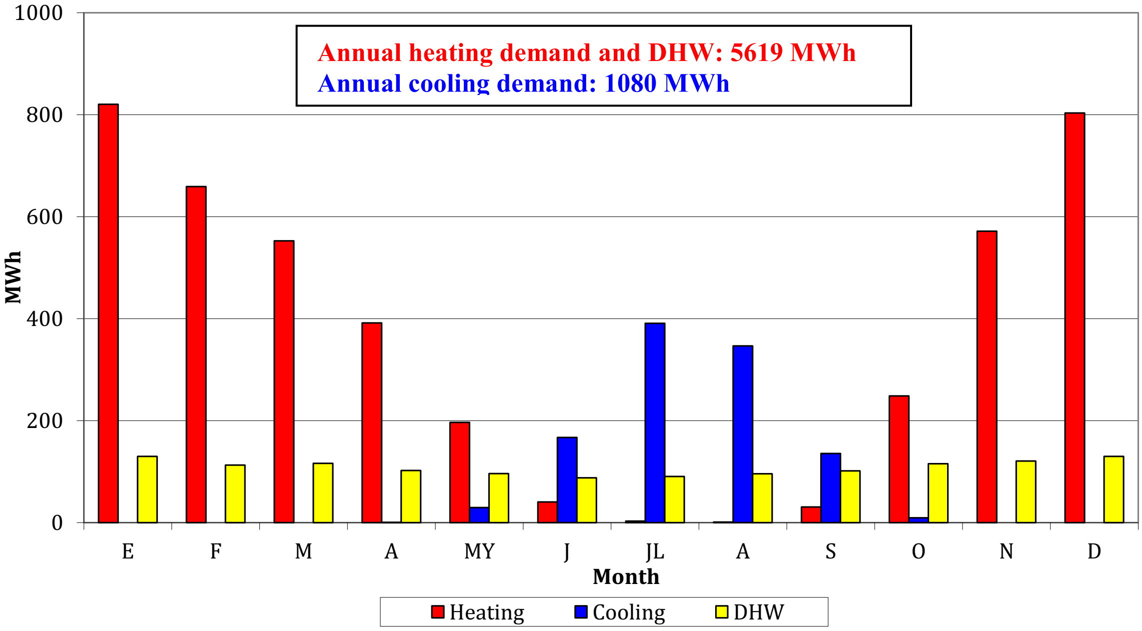

Fig. 4: Heating, cooling and DHW monthly demands for the 1000 residential dwellings in Madrid.

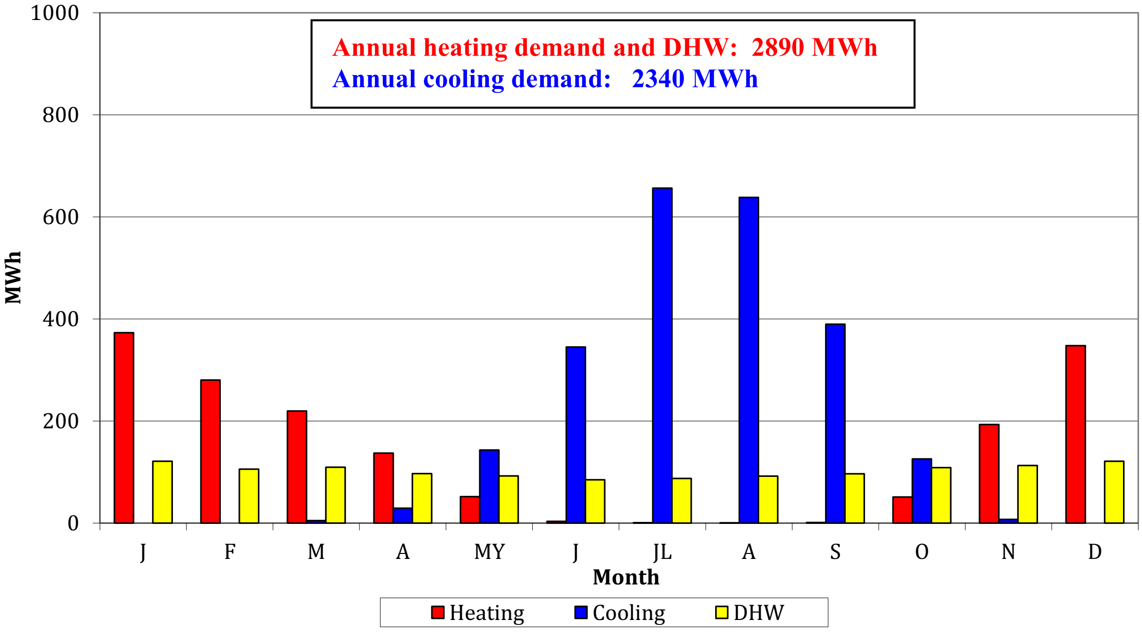

Fig. 5: Heating, cooling and DHW monthly demands for the 1000 residential dwellings in Sevilla.

Tab. 5: Main results for the optimization of the SDHC system with FPC and located in Avila.

Volume (V) m^3	Solar Collector surface (Sc) m^2	Solar yield kWh m^{-2}	Ratio Sc/Energy demand m^2/MWh	Ratio V/Sc m^3/m^2	Solar fraction heating %	Solar fraction cooling %	Specific cost 25 years € MWh^{-1}
10000	4915	664	0.591	2.03	38.0	-	35.59
5000	4114	665	0.495	1.22	32.0	-	34.74
3000	3756	661	0.452	0.80	29.3	-	34.33
1500	3172	674	0.381	0.47	25.4	-	33.89
1000	3421	659	0.411	0.29	26.9	-	33.67
500	3065	666	0.368	0.16	24.6	-	33.48

Tab. 6: Main results for the optimization of the SDHC system with ETC and located in Avila.

Volume (V) m^3	Solar Collector surface (Sc) m^2	Solar yield kWh m^{-2}	Ratio Sc/Energy demand m^2/MWh	Ratio V/Sc m^3/m^2	Solar fraction heating %	Solar fraction cooling %	Specific cost 25 years € MWh^{-1}
10000	3147	1122	0.378	3.18	41.3	-	34.84
5000	2489	1123	0.299	2.01	32.9	-	34.27
3000	2353	1102	0.283	1.27	30.7	-	33.98
1500	2229	1086	0.268	0.67	28.8	-	33.65
1000	2217	1077	0.267	0.45	28.5	-	33.48
500	2176	1069	0.262	0.23	28.0	-	33.29

Tab. 7: Main results for the optimization of the SDHC system with FPC and located in Barcelona.

Volume (V) m^3	Solar Collector surface (Sc) m^2	Solar yield kWh m^{-2}	Ratio Sc/Energy demand m^2/MWh	Ratio V/Sc m^3/m^2	Solar fraction heating %	Solar fraction cooling %	Specific cost 25 years € MWh^{-1}
10000	6062	589	1.161	1.65	71.2	49.6	38.18
5000	5085	598	0.974	0.98	60.3	45.6	35.96
3000	4505	605	0.863	0.67	54.7	40.1	34.86
1500	3823	615	0.732	0.39	48.4	31.5	33.89
1000	3850	611	0.737	0.26	48.1	33.5	33.54
500	3411	616	0.653	0.15	43.9	27.4	33.19

Tab. 8: Main results for the optimization of the SDHC system with ETC and located in Barcelona.

Volume (V) m^3	Solar Collector surface (Sc) m^2	Solar yield kWh m^{-2}	Ratio Sc/Energy demand m^2/MWh	Ratio V/Sc m^3/m^2	Solar fraction heating %	Solar fraction cooling %	Specific cost 25 years € MWh^{-1}
10000	3671	1073	0.703	2.72	72.8	79.6	34.91
5000	3237	1067	0.620	1.54	62.6	76.7	33.55
3000	2878	1070	0.551	1.04	56.1	68.1	32.92
1500	2686	1060	0.515	0.56	52.4	62.0	32.40
1000	2410	1069	0.462	0.41	48.3	53.3	32.21
500	2122	1070	0.406	0.24	43.8	43.1	32.15

Tab. 9: Main results for the optimization of the SDHC system with FPC and located in Madrid.

Volume (V) m^3	Solar Collector surface (Sc) m^2	Solar yield kWh m^{-2}	Ratio Sc/Energy demand m^2/MWh	Ratio V/Sc m^3/m^2	Solar fraction heating %	Solar fraction cooling %	Specific energy cost 25 years € MWh^{-1}
10000	6191	606	0.870	1.62	50.0	56.9	36.69
5000	5021	617	0.705	1.00	42.1	46.4	35.21
3000	4632	621	0.651	0.65	39.5	43.1	34.42
1500	4712	614	0.662	0.32	39.2	46.2	33.76
1000	4065	624	0.571	0.25	35.3	37.6	33.54
500	3812	623	0.535	0.13	33.4	34.4	33.35

Tab. 10: Main results for the optimization of the SDHC system with ETC and located in Madrid.

Volume (V) m^3	Solar Collector surface (Sc) m^2	Solar yield kWh m^{-2}	Ratio Sc/Energy demand m^2/MWh	Ratio V/Sc m^3/m^2	Solar fraction heating %	Solar fraction cooling %	Specific cost 25 years € MWh^{-1}
10000	4516	1054	0.634	2.21	60.9	85.2	38.18
5000	3917	1056	0.550	1.28	52.0	79.2	35.96
3000	3492	1058	0.491	0.86	47.1	69.8	34.86
1500	2916	1073	0.410	0.51	41.2	55.1	33.89
1000	2805	1068	0.394	0.36	39.8	51.6	33.54
500	2408	1071	0.338	0.21	35.5	40.8	33.19

Tab. 11: Main results for the optimization of the SDHC system with FPC and located in Sevilla.

Volume (V) m^3	Solar Collector surface (Sc) m^2	Solar yield kWh m^{-2}	Ratio Sc/Energy demand m^2/MWh	Ratio V/Sc m^3/m^2	Solar fraction heating %	Solar fraction cooling %	Specific cost 25 years € MWh^{-1}
10000	5202	759	0.847	1.92	90.6	38.6	31.85
5000	5118	750	0.834	0.98	85.4	41.3	29.77
3000	5041	746	0.821	0.60	83.1	41.4	28.78
1500	4504	757	0.734	0.33	77.9	35.8	27.87
1000	4274	764	0.696	0.23	75.9	33.4	27.44
500	4112	763	0.670	0.12	73.5	32.1	27.17

Tab. 12: Main results for the optimization of the SDHC system with ETC and located in Sevilla.

Volume (V) m^3	Solar Collector surface (Sc) m^2	Solar yield kWh m^{-2}	Ratio Sc/Energy demand m^2/MWh	Ratio V/Sc m^3/m^2	Solar fraction heating %	Solar fraction cooling %	Specific cost 25 years € MWh^{-1}
10000	3515	1284	0.573	2.84	92.6	51.3	30.61
5000	3463	1263	0.564	1.44	90.3	53.7	28.14
3000	3285	1253	0.535	0.91	85.5	50.3	27.57
1500	3012	1254	0.491	0.50	80.1	45.2	27.03
1000	2787	1264	0.454	0.36	76.5	40.8	26.83
500	2612	1251	0.425	0.19	73.3	36.3	26.83

Finally, table 13 shows a comparison between the usual design values for central solar heating system in central and northern Europe and the SDHC system in Spain. According to these results, it is important to emphasize that in all the cases analysed the collector area of FPC collector per MWh of annual heat demand are lower than the typical design values found in the literature (Schmidt et al., 2003). The main reasons that explain this fact is the higher solar yield due to the more solar irradiation and higher ambient temperatures. In the same way, the specific storage volume per unit area of solar collector has lower values than the typical design guidelines (1.4 -2.1 m^3/m^2) apart from the case of a seasonal storage with a volume of 10000 m^3. Then, as the collector area is relatively lower, that also implies an important reduction in the storage volume. As a result of all the fact mentioned above, the solar energy costs are relatively low and are in the order of magnitude of the cost of the conventional energy source. On the other hand, SDHS with ETC solar collectors show lower values of the specific area and higher values of the solar fraction and specific storage volume due to its highest energy efficiency. Also the specific energy cost is lower although it should be highlighted that this cost strongly depends on the specific cost of solar collectors considered in each case study.

Tab. 13: Comparison of the design guidelines of the central solar heating systems in central Europe and the SDHC systems with seasonal storage in Spain.

Parameter	**Central solar heating with seasonal storage in central and northern Europe with FPC collector**	**SDHC system with seasonal storage in Spain**	
		FPC Collector	**ETC collector**
Minimum system size	> 100 dwellings (each 70 m^2)	> 1000 dwellings (each 100 m^2)	> 1000 dwellings (each 100 m^2)
Collector area (m^2 / MWh heat demand)	1.4 – 2.4	0.4–1.2	0.3–0.7
Storage volume (m^3 / m^2 collector area)	1.4 – 2.1	0.12 – 2.0	0.2–3.2
Annual solar yield (kWh / m^2 collector area)	230 – 350	600–750	1000–1300
Solar fraction (%)	40 – 60	25–60	30–70
Solar heat cost (€ MWh^{-1})	170 – 400	25–40	25–35

4. Conclusions

In this work we analyzed the energy performance and economics of SDHC systems for residential buildings in four Spanish cities. To do so it was necessary to estimate the thermal energy of the buildings using a relatively simple method based on the normalization of the annual energy demand of the cooling and heating demands by the degree-days with a variable base temperature. The results clearly show that SDHC systems could be economically competitive with conventional systems based on the use of fossil fuels and need lower specific area per MWh of the energy demand and lower specific volume per area of solar collector than the solar central systems designed for central and northern Europe. Also is important to note that the storage cost is between a 5% of the total investment for volumes around 500 m^3 and a 20% for volumes around 10000 m^3. Although low volumes of the seasonal storage show the low specific energy cost, the advised values for the specific case of 1000 dwellings of 100 m^2 each one are between 1500 and 3000 m^3. These volumes are a compromise with relatively low cost of the specific energy and a relatively higher solar fraction of heating and cooling. Finally, in the case study analysed, ETC solar technology seems to be the best option.

5. References

AENOR, 2005. Norma UNE-EN 94002:2005. Thermal solar systems for domestic hot water production. Calculation method for heat demand. Asociación Española de Normalización y Certificación (AENOR), Madrid, 2005.

AENOR, 2008 Norma UNE-EN 15459:2008. Energy performance of buildings - Economic evaluation procedure for energy systems in buildings. Asociación Española de Normalización y Certificación (AENOR), Madrid, 2008.

Balaras, C., Grossmann, G., Henning, H.M., Infante Ferreira, C., Podesser, E., Wang, L., Wiemken, E., 2007. Solar Air Conditioning in Europe – an overview. Renewable & Sustanaible Energy Reviews, 11(2), 299-314.

Bauer, D., Marx, R., NuBbicker-Lux, J. Ochs, F., Heidemann, W., 2009 German central solar heating plants with seasonal heat storage. Solar Energy 84, 612-623.

Boermans T., Bettgenhäusser K., Hermelink A., Schimschar S. 2011, Cost Optimal Building performance requirements. Calculation methodology for reporting national energy performance requierement on the basis of cost optimality within the framework of the EPDB, European Council for an Energy Efficient Economy (May, 2011).

CIBSE. 2006, Degree-Days; Theory and application, TM41:2006. The Chartered Institution of Building Services Engineers (CIBSE).

CNE. 2011, Informe mensual de supervisión del Mercado mayorista de gas, Dirección del Gas de la Comisión Nacional de Energía (January 2011)

CTE 2009, Código Técnico de la Edificación, Documento Básico HE Ahorro de Energía, Sección HE-1. Limitación de demanda energética, Ministerio de la Vivienda (2009).

Dalenbäck, J., 2007 Large-scale solar heating and cooling systems in Europe. Proceedings of the ISES World Congress 2007, Beijing, China, 18th to 21st September 2007.

FUNCAS 2011. IPC junio 2011 – Previsiones hasta diciembre 2012. Fundación de las Cajas de Ahorro (FUNCAS). Dirección de Coyuntura y estadística, july 2011.

IDAE, 2009. Escala de calificación energética para edificios de nueva construcción. Instituto para la Diversificación y Ahorro de la Energía (IDAE), Ministerio de Industria, Turismo y Comercio (2009).

López-Villada J., 2010. Integración de sistemas de refrigeración solar en redes de distrito de frío y calor. PhD Thesis. Universitat Rovira i Virgili, Tarragona, Spain.

Nordell B, Hellström G, 2000. High temperature solar heated seasonal storage system for low temperature heating of buildings. Solar Energy 69 (2000) 511-523.

Ochs F., 2010. Modelling Large-Scale Thermal Energy Stores. Shaker Verlag, Aachen 2010.

Peuser, F.A., Remmers K., Schnauss (2002). Solar Thermal Systems. Succcessful Planning and Construction. Solarpraxis, Berlin, 2002.

Pinel P.,Cruickshank C.A., Beausoleil-Morrison I., Wills A., 2011. A review of available methods for seasonal storage of solar thermal energy in residential applications. Renewable and Sustainable Energy Reviews 15 (2011) 3341-3359.

Puig-Arnavat, M., López-Villada, J., Bruno, J. C. and Coronas, A., 2010 Analysis and parameter identification for characteristic equations of single- and double-effect absorption chillers by means of multivariable regression. International Journal of Refrigeration 33 (1) pp 70-78

Rezaie B, Rosen MA, 2011. District heating and cooling: Review of technology and potencial enhancements. Appl Energy (2011), doi10.1016/j.apenery.2011.04.020

Rosen MA, 2009 Combating global warming via non-fossil fuel energy options. Int J Global Warming 2009; 1:2-28

Schmidt T., Mangold D., Müller-Steinhagen H., 2004. Central solar heating plants with seasonal storage in Germany. Solar Energy 76 (2004) 165-174.

TRNSYS 16. 2004. Program Manual, Solar Energy Laboratory, University of Wisconsin, Madison, USA.

Wetter M., 2009. GenOpt®. Generic Optimization Program. User Manual version 3.0.0. Simulation Research Group. Building Technologies Department. Environmental Technologies Division. Lawrence Berkeley Laboratory, May 2009.

Ziegler F, Hellmann H.-M., 1999. An approximate method for modelling the operating characteristics of advanced absorption chillers. Proceedings of 20th International Congress of Refrigeration, 19th to 24th September 1999, IIR/IIF, Sydney, Australia.