ASSSESMENT OF THE BENEFITS OF EMPLOYING THERMAL ENERGY STORAGE IN SPAIN, GERMANY AND EUROPE

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1. Introduction

Thermal energy storage (TES) is currently presented as one of the most suitable solutions in achieving energy savings and preventing damages to the environment. TES potential applications have led to R&D activities and to the development of various technology types according to each situation and many of the applications and/or related technologies involve either direct or indirect use of solar energy. Despite all this, no available data quantifying the benefits of TES is found in literature so far, neither for specific cases nor even on a national scale in countries such as Spain (with a large solar potential), and furthermore on a continental level in Europe. This is why, in order to corroborate the derived energetic and environmental benefits from TES this work intends to provide the first assessment of European TES potential, with a closer outlook for Spain and Germany. Potential and/or current TES applications are classified and their main variables defined. A 10-year scenario with assumed but realistic implementation rates is proposed to provide an idea of the benefits in the immediate future. Load reductions, energy savings, and CO_2 emissions reductions are tackled. Results show that in the case of Europe yearly CO_2 emissions may get to be cut down up to around 6% in reference to 1990 emission levels.

2. Methodology

2.1. Description

Two main large sectors had been distinguished: buildings and industry, with different calculation variables for each case. The cases considered for the buildings sector were seasonal solar thermal storage, district/central heating storage, solar short term storage, and passive cold storage. As for the industrial sector the considered cases were cogeneration, industry waste heat storage, concentrated solar power storage, and industrial waste cold storage at LNG regasification terminals.

To determine the TES potential, the derived thermal load reduction, the thermal/electrical energy savings, and the CO_2 emissions reduction are determined. The thermal load reduction refers to the reduction of capacity from one that would have been consumed under the same working conditions without employing any type of energy storage. The energy savings refer to the heat or cold that is stored and may be realized, not needing to be generated by the application. The CO_2 emissions reduction is the one achieved as a result of reusing stored energy, therefore not consuming fossil fuels or other greenhouse gas emitting energy source during the energy generation, preventing emissions from going to the atmosphere.

2.2. Calculation procedure

Building sector – seasonal solar thermal systems. A seasonal solar thermal storage system is designed to retain heat deposited during the hot summer months for use during colder winter weather. The heat is typically captured using solar collectors, although other energy sources are sometimes used separately or in parallel. The three required parameters to calculate the potential in this type of systems are given by the following equations:

$$L = \frac{Ir \cdot t \cdot (r+n)}{1000} \cdot I_{stge} \qquad \text{(eq. 1)}$$

$$E = \frac{L \cdot y}{1000} \qquad \text{(eq. 2)}$$

$$R_{CO2} = f \cdot E \qquad \text{(eq. 3)}$$

Energy consumption in households is shaped by the characteristics of energy using equipment as well as the thermal integrity characteristics of houses. Renovation of houses for energy purposes, often as part of other modernisation work, also impacts on energy consumption (Capros et al., 2008), as seen in Eq. (1).

The population influences indirectly the energy consumption in buildings, as while population grows very slowly in the EU, the number of households increases faster because the number of persons per household decreases steadily (Capros et al., 2008). Indeed, though the population does not appear explicitly in the proposed equations, based on the previous facts it goes implicit within the building stock variable (B).

The three equations are equally valid for all cases in the building sector, however, some of the parameters are different for specific systems and the respective variations are presented when it corresponds. In Eq. (1), the term (r + n)·B represents the expected/estimated load reduction by any means possible for both renovated and new buildings during a certain number of years (t); the reduction is then multiplied by the storage implementation (I_{stge}) so it may be known how much of that reduction is due to thermal storage. In Eq. (2), this load reduction is simply multiplied by the yearly operating hours (y) in order to obtain the correspondent saved energy. The CO_2 emissions reduction is calculated by multiplying the saved energy (E) by the correspondent conversion factor (f).

Building sector – district and central heating systems. District heating is a system for distributing heat generated in a centralized location for residential and commercial heating requirements such as space heating and water heating. The heat is often obtained from a CHP plant burning fossil fuels but increasingly employing biomass, although heat-only boiler stations, geothermal heating and central solar heating are also used, as well as nuclear power.

A central heating system provides warmth to the whole interior of a building (or portion of a building) from one point to multiple rooms. The heat generation occurs in one place, such as a furnace room in a house or a mechanical room in a large building. The most common method of heat generation involves the combustion of fossil fuel in a furnace or boiler. The resultant heat then gets distributed: typically by forced-air through ductwork, by water circulating through pipes, or by steam fed through pipes. Increasingly, buildings utilize solar-powered heat sources, in which case the distribution system normally uses water circulation.

In this case, the only parameter whose calculation is different is the load reduction, which is obtained through the following equation:

$$L = \frac{H \cdot t}{1000} \cdot \% Ir \qquad \text{(eq. 4)}$$

In this case the load reduction is obtained by multiplying the average heating load of the described systems (H) by the expected/estimated load reduction percentage by means of thermal storage (%lr) during the considered period (t).

Building sector – solar short term systems. A solar short term system consists generically of the following parts: solar collector, solar collector loop, storage subsystem, control subsystem, auxiliary subsystem, and a heat distribution subsystem (Sorensen et al., 2008). From sunrise to sunset, the solar collectors absorb the solar energy and raise the temperature of a heat transfer fluid running through an insulated piping system or collector loop that connects the array of collectors. The heated fluid travels along the piping system until it arrives at a heat exchanger which transfers heat to the water stored in a short-term storage tank or to a central or district heating system. The heat transfer fluid carries on through its loop back to the solar collector system (Pitz-Paal, 2008).

The potential energy savings for these systems are calculated with:

$$L = \frac{t \cdot a \cdot s \cdot (r+n) \cdot B}{10^6} \cdot I_{stge} \qquad \text{(eq. 5)}$$

Eq. 5 shows the saved energy captured by means of employing an area of solar collectors (a) (also related to the collector type), which is to be multiplied by their specific solar gains (s) (which depend on the solar irradiation, that changes with the geographical position) in both new and renovated buildings ((r + n)·B) during the considered time (t). In multiplying this by the storage implementation (I_{stge}), the fraction of the energy savings by using thermal storage is known.

Building sector – passive cold systems. A passive house is a building in which a comfortable interior climate can be maintained without active heating or cooling systems. It is possible to achieve acceptable levels of summertime thermal comfort under the projected warmer future climates using passive cooling measures with modern building materials and modern design methods. Aside from conventional strategies, phase change materials (PCM) present themselves as a viable option in passive buildings (Roberts, 2008). Indeed, though the use of PCM has been studied for other types of energy storage applications, such as in packed bed systems (Rady, 2009), or in single basin solar stills (El-Sebaii et al., 2009), and despite its thermal degradation after long cycling (Mawire et al., 2009), perhaps one of their greatest fields of usage is buildings.

The use of PCM in buildings, as part of the active or passive systems that may optimize the use of energy for heating and cooling purposes, may be particularly determinant (Capros et al., 2008). An example of this was given by Castell et al., 2010, who performed experiments in cubicles holding PCM within a Mediterranean environment (Spain) in order to study the effects of PCM when used for free-cooling purposes; they concluded that the electrical energy consumption was reduced in about 15%, which resulted in a reduction of the CO_2 emissions of about 1–1.5 kg/year m^2. Another experimental study is that of Xiao et al., 2009, who obtained simplified theoretical equations to model the behavior of PCM for energy storage in a lightweight passive solar room, and validated the model with experimental results measured under the climatic conditions of Beijing, concluding that he optimal phase change temperature depends on the average indoor air temperature and the radiation absorbed by the PCM panels; that the interior PCM has little effect on average indoor air temperature; and that the amplitude of the indoor air temperature fluctuation depends on the product of surface heat transfer coefficient and the area of the PCM panels. Despite these studies, more experimental work, such as that performed by Wang et al., 2009, or Sari et al., 2010, on the preparation, characterization, and properties determination of materials for use as PCM for energy storage (whether for application in buildings or other), is required.

PCM application in passive buildings is the case it is dealt with here. Equations governing these storage systems are the same ones employed for seasonal solar thermal systems, adding the achieved electrical energy savings (Eq. 6) as a result of not using electrical air-conditioned equipment at the building:

$$E_e = \frac{E}{COP} \qquad \text{(eq. 6)}$$

The electrical energy savings in Eq. 6 are obtained based on the definition of the coefficient of performance (COP); as in this case the output energy would be the saved electricity (E_e), in dividing the saved thermal energy by the COP, the savings are calculated.

Industrial sector – cogeneration. Cogeneration or Combined Heat and Power (CHP), is the use of a heat engine or a power station to simultaneously generate both electricity and useful heat. It is one of the most common forms of energy recycling. While a conventional power plant emits the heat created as a by-product of electricity generation into the natural environment through cooling towers, flue gas, or by other means, CHP captures the by-product heat for domestic or industrial heating purposes, either very close to the plant, or especially as hot water for district heating with temperatures ranging from approximately 80 to 130 ºC (DEKB, 2010). Equations governing this application are:

$$L_{CHP} = [(1 + n \cdot t) \cdot B] \cdot I_{CHP} \cdot P_{CHP} \qquad \text{(eq. 7)}$$

$$E_{CHP} = \frac{L_{CHP} \cdot y}{1000} \cdot I_{stge} \qquad \text{(eq. 8)}$$

The potential CO_2 emissions reduction is calculated by using the obtained replaced energy in Eq. 3. In Eq. 7, the current building stock is added to the new one during the number of years to be considered ($(1 + n \cdot t) \cdot B$). This term is multiplied by the cogeneration implementation (I_{CHP}), so the number of buildings including cogeneration is known. As this type of application already involves energy recycling, in this case the load reduction is given directly by multiplying the obtained term by the installed power per building (P_{CHP}).

The energy savings only by means of cogeneration itself is calculated by multiplying the load reduction by the yearly operating hours (y), as shown in Eq. 8, and if TES is applied these savings are multiplied by the storage implementation (I_{stge}), so the fraction of savings by means of TES is known.

Industrial sector – industrial heating systems. This category covers three groups of applications: power stations, industry (generically speaking), and transport.

A power station is an industrial facility for the generation of electric power. At the center of nearly all power stations is a generator, a rotating machine that converts mechanical energy into electrical energy by creating relative motion between a magnetic field and a conductor. The energy source harnessed to turn the generator varies widely. It depends chiefly on which fuels are easily available and on the types of technology that the power company has access to. The power sector is the main source of CO_2 emissions in the EU-25, mainly because of the high share of coal consumed in this sector, and represents the main potential for emission at the same time (Matthes et al., 2006).

Industry refers to the production of an economic good (either material or a service) within an economy. European industry spans several industrial sectors, the stronger ones are: automotive, defense, chemicals, biotechnology, and food (Economy watch, 2010). The remaining sectors cover consumer goods, forest products, plastics, agriculture, domestic appliances, furniture, automation and tooling, electronics, metallurgy, textiles, paper and printing, and marine dredging (Industry Europe, 2010).

The transport sector in the EU covers both passengers and freight transport by road, plane or railway and when the sector energetic aspects are addressed, the sector infrastructure is included as well. At this point it is remarkable to mention that as global vehicle production continues to increase, motor vehicles have become important high temperature systems and, furthermore, carbon dioxide emissions due to vehicle usage have a large impact on climate change (Kato et al., 2009). Based on this, TES is considered to have potential to be applied on vehicles mainly due to the utilization of excess heat emitted as an exhaust gas from a muffler and an effluent gas from a radiator, increase of the efficiency of cold production for cabin and container cooling, and providing a heat source of cabin and for managing container heat for electric an fuel cell vehicles (Kato, 2009). It is thought that the potentially stored thermal energy could also be reutilized at the very sector infrastructures.

The potential load reduction (L) for the industrial sector is calculated using Eq. 4 and the energy savings are obtained through the following relation:

$$E = \left(\frac{L \cdot y}{1000} + E_l \cdot t \right) \cdot I_{stge} \qquad \text{(eq. 9)}$$

It may be observed that Eq. 9 is very similar to Eq. 8, only that now, the energy conversion losses from power stations during the considered number of years (t) are added to those energy savings coming from industry and transport only.

Industrial sector – industrial cooling systems. One type of industrial application where TES might be employed is a regasification terminal. A regasification terminal is an industrial installation that lies between that of liquefied natural gas and the natural gas distribution net. In it the process of converting liquefied natural gas into natural gas takes place. In such terminals, the gas load from the methane ships is reintroduced into cryogenic tanks, where the gas initial temperature (-160 ºC) is maintained.

During the regasification, the gas is transported towards the vaporization systems, where temperature is risen by using sea water, thus turning liquid into gas (Wikipedia, 2009). It is the amount of cold the gas gives off during this process the one which is wasted, since the sea water is directly returned to the sea after completion of the process. Currently, six countries in Europe feature this type of terminals, totalizing a number of 15 plants: Spain (Barcelona, Cartagena, Huelva, Sagunto, Mugardos, and Bilbao), Belgium (Zeebrugge), France (Fos-sur-Mer, Montoir), Italy (Panigaglia, Porto Viro), Greece (Revithoussa), and the UK (South Hook, Dragon, both in South Wales, and Grain) (King and spalding, 2011).

The proposed equation for this case is:

$$E = \frac{F \cdot \rho \cdot c_p \cdot \Delta T \cdot y \cdot t}{10^6} \cdot I_{stge} \qquad \text{(eq. 10)}$$

Input data for Eq. 10 are those referred to the sea water employed during the regasification process, while the density and specific heat are determined by the fluid itself, the volume flow and temperature increase are terminal generic design parameters.

The heat absorbed by the water is simply obtained by multiplying the mass flux (F·q) by its specific heat (c_p) and the temperature increase (ΔT). When this heat is multiplied by the yearly operating hours (y) and the considered number of years (t), the absorbed energy during the considered period is obtained. If TES is applied, a fraction of this energy would be saved, so if the energy is multiplied by the storage implementation (I_{stge}), this fraction may be known.

Industrial sector – concentrated solar power plants. Concentrated solar power plants produce renewable heat or electricity (generally, in the latter case, through steam) by using lenses or mirrors and tracking systems to focus a large area of sunlight onto a small area. The concentrated light is then used as heat or as a heat source for electricity generation. A wide range of concentrating technologies exist, and each concentration method is capable of producing high temperatures and correspondingly high thermodynamic efficiencies, but they vary in the way that they track the Sun and focus light (Luzzi and Lovengrove, 2004). If TES systems are part of the plant, solar heat collected during the daytime can be stored in systems based on concrete, steam, molten salt, ceramics, or PCM. At night, it can be extracted from the storage to run the power block continuously (Viebahn et al., 2008).

The main benefit from employing TES in CSP plants is the electrical energy which does not have to be generated by the plant during its regular operation but thanks to the storage system. Even just a few hours of thermal storage are sufficient to allow CSP plants to serve up to around 70% of the intermediate and peak load, however, thermal storage cannot fulfill the role of supplying backup power for days in which direct irradiance is not sufficient to operate the CSP solar field (Zhang et al., 2010). As it is an energetic parameter, the electrical energy savings are simply given by:

$$E_e = \frac{P_{N,stge} \cdot y_{stge} \cdot t}{1000} \qquad \text{(eq. 11)}$$

Eq. 11 shows that the savings are calculated by simply multiplying the nominal power ($P_{N,stge}$) by the TES system yearly operating hours (y_{stge}) and by the considered number of years (t). As seen, only parameters related to plants holding TES are involved and not those from other operating plants, though as it will be explained latter, data from plants without TES are used to calculate the operating hours of plants with TES.

The CO_2 emissions reduction is obtained by using Eq. 3.

2.3. General assumptions

The assumed baseline scenario quantifies the TES energy savings over the period to 2020 for the EU (employing EU-25 data mainly), arising from a continuation of the previously described background and taking those current trends in terms of energy, transport and CO_2 emissions will continue along the considered period, which has led to some specific assumptions:

- The energy mix is taken as constant.
- Within the building sector, energy consumption and space heating needs are expected to experience a very slow increase in the medium term (Capros et al., 2008), which is why these needs are taken as constant.
- Input data within the industrial sector is also taken as constant as they are also expected to go through very slow variations in the medium term.

2.4. Input data obtaining and specific assumptions

CO_2 emissions factor. The variable *f* is required to obtain the potential CO_2 emissions reduction. This is done based on the German, Spanish and European energy mixes respectively, weighing the individual factors respect from the energy source usage percentage. As example, input data and obtained factors for Spain (Ministerio de Industria, Turismo y Comercio, 2008; Asociación de Investigaciones y Cooperación Industrial de Andalucia, 2009) and Europe (US Energy Information Administration, 2010; European Commision, 2009) are shown in Table 1. As for the electrical CO_2 emissions reduction factor, it is given directly by data sources. The factors are: 649 g CO_2/kW he for Spain [24] and 476 g CO_2/kW he for Europe (European Commission, 2009).

Tab. 1: Determination of the weighted CO_2 emissions factor for Spain and Europe.

Energy source	Consumption percentage		Conversion factor (g CO_2/kWh_{th})	
	Spain	Europe	Spain	Europe
Natural gas	22%	24%	204	202
Fuel oil	48%	39%	244	279
Coal	14%	17%	347	351
Weighted factor			251	271

Building sector input data. The data initially required is the building stock, the rate of renovation, and the rate of completion of buildings. This type of data is available in national statistical sources of information. However, if the renovation and new buildings percentages are not directly found, they may be calculated by using data from past years, an example employing EU-25 data (mainly provided by Eurostat, 2009) is shown in Table 2.

Tab. 2: Example of calculation of the housing new buildings completion percentage in the EU-25.

Period	Building stock (*B*) (thousands of buildings)	New buildings (thousands of buildings)	Buildings rate of completion (*n*)
2003	188,313	---	---
2004	189,557	1,244	0.66%
2005	192,996	3,439	1.81%
2006	195,593	2,597	1.35%
n mean value			1.27%

Both for Spain and Europe the percentages have been assumed to be equal for housing and non-housing buildings when necessary.

Other necessary data are the load reduction, the storage implementation percentage, the yearly operating hours and the scenario covered period of time. A short scenario period is desired, so this last variable has been set to 10 years both for Spain and the EU. The storage implementation percentage is to be assumed in all cases, though if existing data is on hand it may be used as well. The load reduction must be estimated. This may be done through the heating and cooling demands or through the actual heating and cooling consumptions if more suitable, the average building area, and the yearly operating hours for each system. When dealing with passive cold systems the COP is required, this variable value is that of commercial air-conditioning equipment and again an average value may be assumed. Regarding solar short term systems, the solar collector area per building (average values may be used or assumptions taken as the case) and solar collector utilized solar gains are required too. The solar gains are given indirectly by the yearly irradiation at the considered region and the solar collectors features. Correspondent data sources are to be consulted to the fore. In reference to district/central heating systems, the heating load and load reduction percentage are required. While this last one may be assumed, the heating load may be obtained directly when available or calculated based on the heating demand.

Industrial sector input data. As stated in Eq. 11, a necessary parameter is the yearly operating hours during which the TES system is operational; so this value was estimated based on the energy generated by those plants with TES systems and the energy generated by an equivalent plant without TES systems.

First, the energy generated during storage hours must be obtained for each plant holding a storage system:

$$E_{stge} = E_{p,stge} - \frac{P_{N,stge}}{P_{N,nostge/ref}} \cdot E_{nostge/ref} \qquad \text{(eq. 12)}$$

The goal is to determine which fraction of the predicted energy generation in CSP plants is generated thanks to TES systems. For this, a plant not featuring TES is selected as a reference and each CSP plant nominal power is compared to that of the reference, using the result as a weighing factor. This process is to be followed and done for each plant. At the present case the chosen reference has been the Alvarado I plant in Spain. Then, the average storage operating hours are obtained by dividing the calculated energy generation amounts by the sum of each plant nominal power:

$$y_{stge} = \frac{\sum_{i=0}^{n} E_{stge,i}}{\sum_{i=0}^{n} P_{N,stge,i}} \qquad \text{(eq. 13)}$$

Obtained results for EU-25 are shown in Table 3, which gathers data about the found plants at the time of elaborating this document.

3. Results

Global TES potential results are shown in Table 4. The breakdown of the obtained values by sector and system is shown in Table 5. Load potential reductions obtained for Germany and Spain are 8% and 9%, respectively, from the European reduction value. Should this potential values become a reality, thermal and electric capacities of the energy equipment to be installed in the near future at the considered sectors would be lower than those projected, with parallel benefits aside from those derived from TES itself. The potential savings account for 8% and 7% at the EU-15 and EU-27, respectively, giving an approximate average value of 7.5% energy savings as a result of TES application.

It may be appreciated that Spanish share of potential electrical savings gets to 20% of the potential whole for the EU-25, highlighting that, as seen in Table 3, Spain is the country where most CSP plants are operative and where a large number of buildings may be found, aside from the regasification terminals it holds (whose main contribution to the TES potential is the saving of electricity), and therefore establishing it as the nation which features more potential when it comes to saving electrical energy. Savings account modestly for 0.1% both at the EU-15 and EU-27, mainly because of the still low implementation of the applications which may hold TES and provide electricity savings simultaneously (passive houses, CSP plants, and regasification terminals), rather than the storage implementation itself. As there are many CSP plants under project or during the last stage of design, particularly in Spain (NREL, 2011), it is expected that TES is taken under consideration. Likewise, both if the passive house application and the regasification terminals would spread out more, this contribution to energy savings would be expected to grow perhaps considerably more.

Tab. 3: Concentrated solar power plants data and estimated results.

Country	Plant	Nominal installed power (MW_e)	Includes thermal energy storage	Predicted yearly energy generation (GWh_e)	Estimated yearly energy generation during storage operating hours (GWh_e)	Storage yearly operating hours (h)
Spain	PS10	11	X	26	4	324
	PS20	20		50.6		
	Andasol 1	50	X	170	68	1360
	Solar 3	15	X	105	74	4960
	Puertollano	50		114.2		
	Alvarado I	50		102		
	Puerto Errado I	1.4	X	2.8	0.5	330
Italy	Archimedes	4.72	X	9.2		
France	Solenha	12	X	60		
Germany	Jülich	1.5	X	1	12.5	2640
					48	3960
					0.5	330
y_{stge}						2164

Tab. 4: TES potential benefits for Spain, Germany, and the EU-25.

Parameter	Spain	Germany	EU-25
Load redction - L (MW)	541,266	480,844	5,854,139
Replaced thermal energy - E (GWh)	826,263	662,291	9,527,227
Replaced electrical energy - E_e (GWh_e)	3,431	Not available	17,526
CO_2 emissions reduction - R_{CO2} (T)	207,670,938	165,572,663	2,579,088,559

Tab. 5: TES potential results breakdown by sector and system for Spain, Germany, and the EU-25.

System	Parameter	Spain	Germany	EU-25
Buildings – Seasonal solar thermal	L (MW)	2,294	1,001	25,287
	E (GWh)	4,186	1,801	46,150
	R_{CO2} (T)	1,049,089	450,322	12,517,676
Buildings – District/central heating	L (MW)	19,642	57,000	1,453,863
	E (GWh)	35,846	87,384	2,326,182
	R_{CO2} (T)	8,983,685	21,845,972	630,957,558
Buildings – Solar short term	L (MW)	135,093	16,011	416,180
	E (GWh)	140,883	2,664	319,269
	R_{CO2} (T)	35,307,388	666,008	86,599,153
Buildings – Passive cold	L (MW)	699	Not available	9,944
	E (GWh)	1,275	Not available	18,148
	E_e (GWh_e)	472	Not available	6,481
	R_{CO2} (T)	306,519	Not available	3,085,135
Industrial sector – CHP	L (MW)	9,354	5,888	187,790,
	E (GWh)	6,314	5,299	126,758
	R_{CO2} (T)	1,582,403	1,324,732	34,382,153
Industrial sector - Heating	L (MW)	374,185	400,944	3,761,074
	E (GWh)	632,528	565,143	6,659,335
	R_{CO2} (T)	158,521,473	141,285,629	1,806,289,626
Industrial Sector – Cooling	E (GWh)	5,231	Not available	31,386
	E_e (GWh_e)	1,495	Not available	8,967
	R_{CO2} (T)	969,980	Not available	4,268,512
Industrial sector CSP	E_e (GWh_e)	1.464	Not available	2,077
	R_{CO2} (T)	950,401	Not available	988,747

Contributions from Germany and Spain to potential CO_2 emissions reductions at the EU maintain proportions as observed with the previously evaluated parameters. Aside from the 2005 reference year, 1990 is also considered as from that year on, greenhouse gas emissions began to be measured as stated at the Kyoto Protocol (Dell and Rand, 2001). The potential reductions account approximately a 6% and 5% both for 1990 and 2005 at the EU-15 and the EU-27; therefore, an average CO_2 reduction of 5.5% within the EU might be expected.

4. Conclusions

A linear model to estimate the potential TES impact in terms of load, energy, and CO_2 emissions reductions, has been developed. The potential for Germany, Spain and the European Union, considering a 10-year scenario has been calculated, so current circumstances within the addressed sectors could be still valid and assuming low but realistic storage implementation rates.

It has been determined that the potential load reduction at the EU may be of 1160,695 MWth during the next 10 years, which may exert a strong influence over power capacities to be installed over that period. Germany and Spain parts in this reduction are of 8% and 9%, respectively. Yearly potential energy savings at the EU is estimated to be 7.5%. Regarding electrical energy savings, Spain has got a contribution of 20% of the overall savings at the EU, which account for a 0.1% of the electrical energy consumption. Finally, the estimated potential CO2 emissions reduction in the EU is an average of 5.5% (based on 1990 and 2005 levels).

5. Nomenclature

I	implementation percentage
N	new buildings yearly construction completion percentage
r	buildings yearly renovation percentage
a	solar collector area per building (m2/building)
B	building stock
c	specific heat (kJ/kg ºC)
COP	coefficient of performance (–)
E	replaced energy (GWh_{th})
F	water volume flow rate (m^3/s)
f	weighted CO_2 emissions conversion factor (g CO_2/kWh_{th})
H	average heating load (GW_{th})
L	potential load reduction (MW_{th})
lr	expected/estimated load reduction per building (kW_{th}/building)
j	expected/estimated load reduction percentage per building
P	installed power per building or installation (MW_{th})
R	greenhouse gas emissions reduction (T)
s	solar collector utilized solar gains (kWh_{th}/m^2)
t	number of years of the considered scenario (–)
T	temperature (ºC)
y	yearly operating hours (h)
Greek letters	
Δ	increase
ρ	water density (kg/m3)
Subscripts	
th	thermal value
e	electricity associated value
eq	equivalent value
CO_2	CO_2 associated value
CHP	combined heat and power (cogeneration) associated value
i	assigned order to data within summation calculations
av	average value
l	losses associated value

p	constant pressure associated value
N	nominal value
stge	storage associated value
p,stge	predicted value associated to storage
N,stge	nominal value associated to storage
N,nostge/ref	reference nominal value not associated to storage
nostge/ref	reference value not associated to storage

6. Acknowledgements

This work was partially funded by the Spanish government (Project ENE2008-06687-C02-01/CON). The authors would like to thank the Catalan Government for the quality accreditation given to their research group (2009 SGR 534). The authors would like to thank Mr. Rolf Stricker for his contribution regarding the Germany data and the initial work development.

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