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THERMAL STORAGE COUPLED TO A GROUND SOURCE HEAT PUMP IN A PUBLIC SERVICES BUILDING

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SUMMARY/ABSTRACT

Thermal storage may be a particularly attractive approach in service sector buildings, particularly for space conditioning, since it can help to reduce the electricity costs taking advantage of variable electricity rates while helping the grid to overcome the intermittent output of renewable energy. The aim of this paper is to describe globally the thermal storage system, which will be coupled to the ground source heat pump (GSHP), which was installed in a public building in Coimbra within the European Project from FP7 – Ground-Med. This project aims to demonstrate a high seasonal performance factor for ground source heat pumps (GSHP) that will be installed in pilot buildings in southern Europe.

INTRODUCTION

The increasing integration of intermittent nature renewable energy has led to the need to consider new ways of managing the grid since often this type of supply is out of line with periods of increased demand. It is therefore necessary to develop solutions that allow the flexible integration of production with energy consumption. Hence, thermal storage with phase change material can be one of the potential solutions for this problem [Zhang et al., 2007]; [Omagari et al., 2008]; [Stadler, 2008].

In Portugal, during the night in rainy and windy winters, the production of electricity from renewable sources exceeds the needs of electricity consumption. For this reason, the study of an efficient thermal energy storage system for space heating is very important.

The pilot building in Coimbra, where the GSHP was installed, is a public service building with four floors where three floors are mainly offices. The GSHP was designed and installed to satisfy the thermal needs of the 3rd floor. This is the floor which presents higher thermal gains and losses due to its connection to the roof and due to the large glass area. This floor has 22 rooms (offices) and approximately a space conditioned area of 600 m2. The space conditioning system, which was installed before in this floor, was composed of two units (variable velocity compressors) with a heating capacity of 31,5 kW.

Figure 1: Pilot Building in Coimbra.

The main electricity consumption is due to space conditioning systems, office equipment and illumination. The period occupancy is from 8 AM to 7 PM as represented in the load profile of the building presented in figure 2.

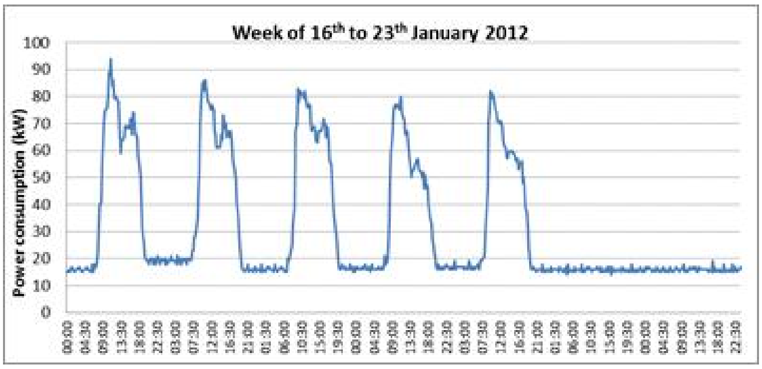

Figure 2: Electrical Load profile of the building – Mid-winter.

It is possible to observe that the peak load of the building occurs in the morning, when workers turn on all the electric equipment, including the space heating system. This peak load period is coincident with the national peak load demand period, where the electricity and the power have a higher price.

For the reasons presented before, the installation of a thermal storage will reduce the electricity bill of the building (moving consumption to lower cost off-peak periods) and reduce the peak power. For this purpose, it was decided that a latent heat thermal energy storage (LHTES) will be coupled to the GSHP.

Energy storage with phase change material (PCM) has a lot of advantages over sensible systems because of the lower mass and volume of the system, the energy is stored at a relatively constant temperature and energy losses to the surroundings are lower than with conventional systems [Rousse et al., 2009]; [Benli & Durmus, 2009].

The global model of the entire system, including the GSHP, the hydraulic circuits, the fan coils and the storage tank it is being developed using the computational tool, the Transient System Simulation Program – TRNSYS.

At this stage, the thermal storage capacity and the tank dimensions are already defined. The PCM is already selected and the electricity costs reduction was estimated, which will be presented in next sections.

1 THERMAL STORAGE CAPACITY

The thermal storage capacity was determined based on the estimated thermal load diagram of the 3rd floor, the electricity rates period and the cost of the thermal storage system. A total thermal storage strategy is very expensive, since in Portugal the heating season is about twelve weeks. This way, the thermal storage was defined as a partial-storage strategy to meet thermal needs during the day with priority during peak demand periods.

Taking into account the peak demand period in the morning, the thermal storage should be designed to meet at least the thermal needs during this period, which is actually 1,5 hours from 9 AM to 10:30 AM. To better understand this idea it is presented the contracted electricity prices and the estimated thermal load profile during a cold week in winter.

Table 1: *Contracted electricity prices of the building.*

Period	**Period**	**Electricity prices (€/kWh)**	**Peak Power Prices (€/kW.day)**
Peak period	9 AM to 10.30 AM 6 PM to 8:30 PM	0,2078 €/ kWh	0,4025 €/ kW
Middle peak period	8 AM to 9 AM 10:30 to 6 PM 8:30 PM to 10 PM	0,1112 €/ kWh	
Off peak period	10 PM to 2 AM 6 AM to 8 AM	0,0732 €/ kWh	
Special off peak period	2 AM to 6 AM	0,0680 €/ kWh	

Figure 3: Thermal Load profile of the 3rd floor – winter.

After some simulations it was possible to determine that it is need a thermal capacity around 100 kWh to guarantee that the GSHP will not operate to meet the thermal needs during the peak and more expensive electricity period. The peak period have two penalizing rates, one for the electricity consumption and another one to the power demand.

The following figures show two different daily load profiles from figure 3, using thermal storage contribution.

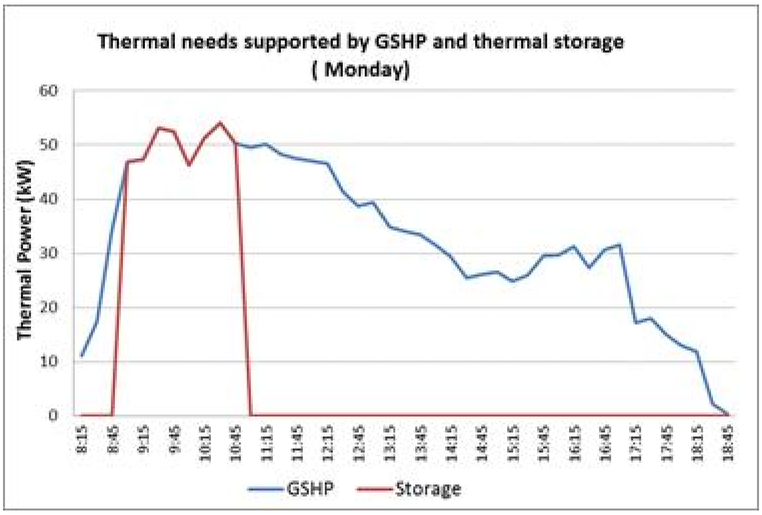

Figure 4: Capacity Storage of 100kwh supports thermal needs during 2h.

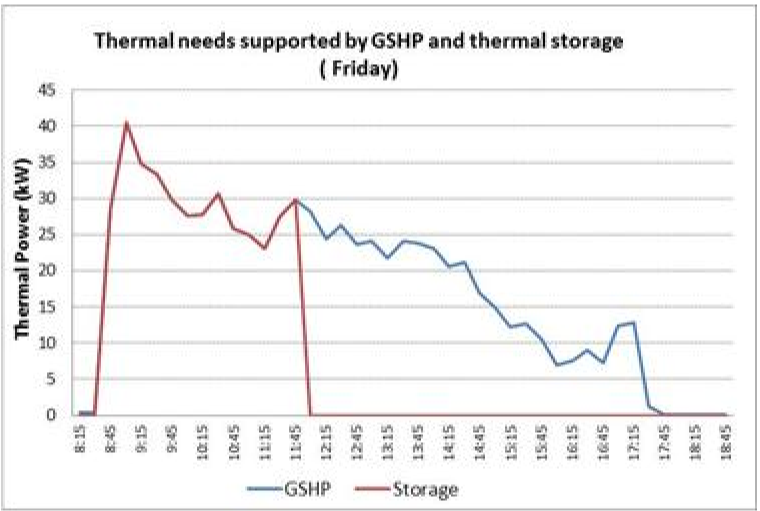

Figure 5: Capacity Storage of 100kwh supports thermal needs during 3,5h.

As it can be seen in the previous figures a thermal storage capacity of 100 kWh can support the thermal needs of the 3rd floor during the peak period in a typical cold day. In less cold days in winter the thermal storage may satisfy most of the thermal necessities.

2 THERMAL STORAGE SYSTEM

2.1 Phase Change Material

The desired operating temperature range is one of the most important criteria for the selection of phase change heat storage materials, since the heat transfer rate in LHTS unit and thus the performance of the system mainly depends on the difference between the heat transfer fluid (HTF) temperature and the melting point of PCM [Agyenim et al., 2010].

Taking into account that the GSHP and the fan coils were design to operate with a supply temperature of 40°C and a return temperature of 35ºC in the space heating loop and that it is needed at least a delta T around 5ºC to charge and discharge happens between the water and PCM material [7], the melting point range must be within the range of 44 – 48ºC, ideally 45ºC. It was decided to use a commercial encapsulated PCM which was already tested and used in others real in Europe.

PCM name	Type of Product	Melting point (ºC)	Heat of Fusion (KJ/kg)	Specific Heat (kJ/kg K)	Thermal Cond. (W/m K)	Encapsulation	Supplier
RT42	Paraffin	41	174	2,1	0,2	CSM Panel (Rectangular)	Rubitherm (Germany)
A42	Organic	42	230	2,20 - 2,22	0,21 - 0,2	Ball-Ice (Spherical)	PCM products Ltd (UK)
S44	Salt hydrate	44	105	1,61	0,43	Tube-Ice (Cylindrical)	PCM products Ltd (UK)
S46	Salt hydrate	46	190	2,41	0,45	**Flat-Ice (Rectangular)**	**PCM products Ltd (UK)**
Climsel C48	Sodium Sulphate, Water and Additives	48	226,8	3,6 1Wh/kg °C	0,5-0,7	-	Climator (Sweden)
Latest™48S	Salt hydrate	48	>230	2	0.6	Panels / balls	PCM Energy P. Ltd (India)

Figure 6: PCM's available in the market within the desired melting point range.

The S46 salt hydrate was identified as the being the most suitable candidate for heat storage. Paraffin's have a very low thermal conductivity, around 2 or 3 times lower than salt hydrates. The S44 salt hydrate has a lower heat of fusion (105 kJ/kg) and it is more expensive.

The selected PCM is a hydrate salt (sodium thiosulfate pentahydrate) with a melting point of 46ºC and a heat of fusion of 190kJ/kg. This PCM is already available in rectangular plastic containers that can be stacked on top of each other forming a self-assembling large heat exchanger within the tank.

Figure 7: PCM encapsulated in rectangular plastic containers [PCM Products Ltd, 2011].

2.2 Thermal Storage Tank

The storage unit will consist of a tank, with a total volume of 3,5m3 filled with 400 containers of a Phase Changing Material (PCM) resulting in a useful storage capacity of 100kWh. Forty percent of the tank volume must be occupied by the heat transfer fluid (water) to guarantee a good transfer heat rate [PCM Products Ltd, 2011].

The rectangular containers will be self-assembling in a matrix of 4 containers in length and 3 containers in width, with 33 layers to have around 400 containers. Taking into account the container dimensions and that it is needed 0,5m for each tank header to provide uniform flow across the section tank, the tank has a length of 3m, a width of 0,8m and a height of 1,5m as internal dimensions. The external dimensions must include around 100mm of insulation. The projected tank is presented in next figure.

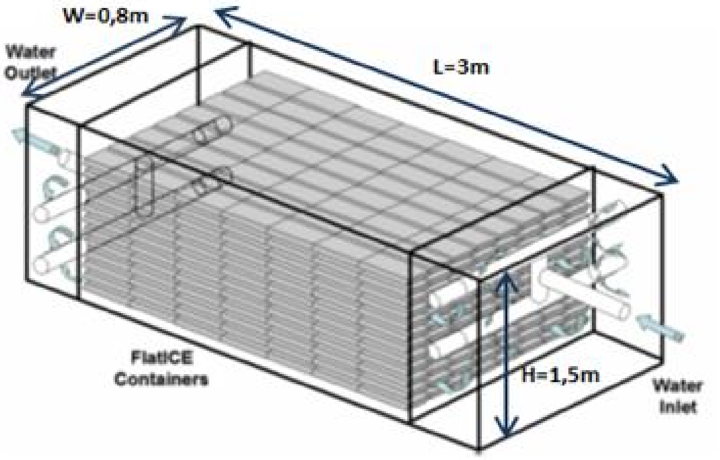

Figure 8: Projected storage tank.

2.3 Thermal Storage operation modes

As already explained the storage system will be used as a partial-storage strategy to meet thermal needs during the day with priority during peak demand periods. In this way the system will operate in different modes:

- Space conditioning directly by GSHP

- Space conditioning by the storage tank

- Space conditioning from both systems during day

- Charging of the thermal storage mode by GSHP during night.

With the Thermal Storage installed a whole new group of valves should be controlled in order to charge / discharge the tank to make the entire system more efficient. Therefore a controller is required to automate the valves that are responsible to change the pipe circuitry (Figure 9) from the GSHP to charge the Thermal Storage during nigh, to divert the periods when the electricity is more expensive, taking advantage of the power available from renewable energy such as wind power. Since the measuring system required for the GroundMed project is using high efficient and powerful equipment like the National Instruments cRIO-9074, we are also using this technology to perform the thermal storage control with a low investment in extra hardware.

This control system has access to temperatures inside and outside the tank, date and time and the ability to control all the electrical valves, deciding the ideal time to charge and discharge the Thermal Storage.

Figure 9: GSHP Measurement and Control System of the GroundMed Coimbra demo site.

Next figure presents de internal hydraulic loop, which allow the four operation modes referred.

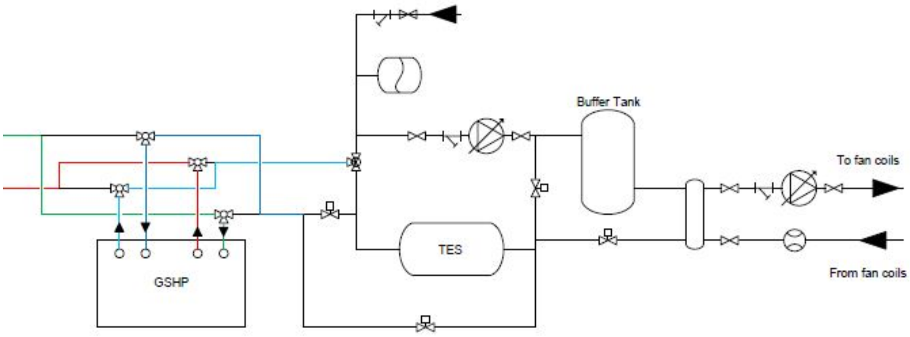

Figure 10: Internal hydraulic loop with the storage tank.

The global model of the entire system, including the GSHP, the hydraulic circuits, the fan coils and the storage tank it is being developed using the computational tool, the Transient System Simulation Program – Trnsys.

Depending on the simulations of the space heating system to meet the thermal requirements of the building, the operation of heat storage system will be optimized, in way to optimize the coefficient of performance of the GSHP, as well as the operating costs, according to the electricity prices. Simulations will be carried out with current market prices and with scenarios of dynamic electricity prices.

Experimental tests will be carried out with the aim to validate the mathematical model, to evaluate the control system performance and to evaluate the efficiency performance of the GSHP system with and without the TES system using different control strategies.

3 CONCLUSION

Thermal storage has been considered and demonstrated from several years a good strategy to improve the power demand profile leading to a reduction of primary energy and of grid operation costs, a higher reliability of the electrical grid and to a reduction of the consumer's electricity bill [Kennedy et al, 2009]; [Qureshi et al., 2008]; [Stadler, 2008]; [Omagari et al., 2008]. Nowadays, with the increase of intermittent energy resources, the trend of a significant increase of electricity prices and the dynamic electricity strategy, thermal storage assumes a higher importance.

Although the GSHP is already a very efficient technology for space conditioning, the addition of a thermal storage still be an attractive solution which leads to additional benefits for all the electric system and for the consumer. In this case study it was estimated a reduction of around 50% of the electricity costs for space heating during the winter period.

At the end of this project it is expected to demonstrate that the combination of both technologies will result on a high efficiency solution for space conditioning system of the Coimbra building. Furthermore, it may have a large application potential in Europe, with the additional benefit of using intermittent energy, storing this energy to be consumed when necessary, thereby contributing to a more efficient and cost-effective operation of the electric system.

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