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STUDY OF A 20'000 m^3 SEASONAL HEAT STORAGE FED BY SOLAR COLLECTORS

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ABSTRACT

This study deals with an underground seasonal heat storage built under a large industrial building and operating between 5 and 35 °C. We present its characteristics, results obtained after 20 months of detailed monitoring, as well as a modeling approach of such a storage.

KEYWORDS

Seasonal storage; heat storage; solar storage; underground storage; diffusive storage.

INTRODUCTION

A large industrial building (75'000 m^3) built near Geneva (Marcinhès, Meyrin) was carefully designed for efficient energy use by Matthey and Roulet (1986, 1987). It involves 950 m^2 of flat plate collectors on the roof (for heating and domestic hot water), an underground seasonal heat storage (20'000 m^3) with 258 vertical heat exchangers (or wells) 14.5 m deep and 2.3 m apart below the building, solar gains through passive solar walls (two double glazing), a heat pump, auxiliary furnaces (oil, gas and wood), floor heating as well as conventional heating devices. The fuel consumption should be below 150 MJ/m^{2}y, where the reference area is the heated floor area.

The storage is fed by the solar collectors, mostly in summer time and occasionally during winter when excess heat is available. Heat is extracted from the storage by the heat pump in winter time when heating is required. Solar gains may also be driven directly to the heat pump. The storage, and consequently, the solar collectors are operating at low temperature (typically 5-35°C for the storage).

We are monitoring the entire building in detail. The solar collectors are working properly and as expected. They were specially built as part of shed structures and they constitute the waterproof cover of the flat roof of the building. They are single glazed collectors with selective absorbers. Our measurements show that they are characterized by an optical efficiency of 0.74 and by thermal losses (including piping of the array) of 5.1 W/m^{2}K.

The gas powered heat pump (~200 kW) failed most of the first winter operation period (1989-1990), because of a control problem. The solar collectors, therefore, had to be covered in summer 1990, in order not to exceed the temperature limits (~50 °C) for the plastic tubes of the storage. The heat pump is now working properly with an overall coefficient of performance (useful heat/gas energy content) of around 1.7 which is quite satisfactory.

We now focus on the underground seasonal storage for which measurements started May 1989. This study is still going on, but we can already present some interesting and preliminary results.

THE UNDERGROUND STORAGE

The underground storage is located under the building and separated from the building by a thermal insulation layer. Its characteristics are described in the following table.

TABLE 1 Characteristics of the Underground Storage

Volume	20'000 m^3
Horizontal area	1'400 m^2 (44 m x 32 m)
Upper insulation	5 cm of foam glass
Ground	dry moraine
Number of boreholes	258
Borehole diameter	114 mm
Borehole depth	14.5 m
Distance between boreholes	2.3 m (square network)
Total length of boreholes	3740 m
Heat exchanger	4 tubes, i.e. 2 U-tubes/borehole
Tube diameter	32 mm
Tube material	polyethylene
Thermal contact between tubes and ground	fine sand + water injection at the head of the boreholes if or when necessary
Total length of tubes	15500 m
Tube connections	by series of 13 wells 2 series in parallel for both U tubes of each well (in case of leak, one series can be shut off)
Thermal stratification	along storage radius, heat injection: fluid goes from center to periphery, heat extraction: fluid goes from periphery to center
Heat transfer fluid	water
Maximum injection power	200 W per m of borehole
Maximum extraction power	25 W per m of borehole
Temperature range	~ 5-35 °C
Annual stored energy	~ 400 MWh

MEASUREMENTS

We restrict ourselves, in this paper, to the measurements concerning only the underground storage.

Temperature measurements are achieved by the use of platinum resistances (Pt-100) with an accuracy of the order of 0.1 °C.

We measure continuously, with the data acquisition system devoted to the entire building, the total heat flow going in and out of the storage (i.e. 1 flowmeter and 2 temperature sensors). We also measure, with the same system, the heat flow for the first, the second and all wells of a series of 13 wells (i.e. 1 flowmeter and 4 temperature sensors). We also recently connected 3 additional channels for temperature measurements at the interface between the storage and the building, in order to investigate thermal gradients and related thermal losses at the upper surface of the storage (these losses are recovered as heating by the building).

We measure once a week, 5 vertical temperature profiles in 5 special wells located between and equidistant from adjacent storage boreholes. The first well is in the middle of the storage, the second one at half a radius of the storage and is considered as representative of the whole storage, and the 3 last ones are aligned along a same radius at the periphery of the storage in order to investigate temperature gradients and heat losses from the storage. Each measurement well is equipped with 10 temperature sensors at different depths from the upper surface to a few meters below the storage (0.5, 1, 2, 6, 10, 13, 14, 15, 16.5 and 19 m). The temperature sensors are mounted in a plastic tube (diameter: 30 mm), filled up with glycerine to insure a good thermal contact and to prevent thermal convection. These weekly measurements are performed by hand with a special device.

RESULTS

We show on the 3D-plot of Fig. 1 how the vertical temperature profile of the storage (well 2) has evolved with time. Because of the heat pump failures, the storage temperature did not return after the first winter of operation to its expected minimum value (5-10°C). Various gradients appear clearly on such a figure.

On Fig. 2 we present vertical temperature profiles for the 5 monitored wells at the same time (or date), during a loading period (a) and during an unloading period (b). Temperature gradients at the periphery of the storage appear clearly and may vary with time.

We show on Fig. 3 how the average temperature of the storage has evolved versus time (a) and versus the heat injected into the storage (b). We consider, as a preliminary and arbitrary estimate, the average temperature of well 2 for the depths 6 and 10 m as representative of the storage. The injected heat includes negative contributions related to extracted heat. On Fig. 3b the storage losses during one cycle can be evaluated by the fact that the storage temperature after one cycle returns to the same value; for instance ~300 MWh at 25 °C, which corresponds (see Fig. 3a) to a 13 month period (particular case of an annual cycle, not yet stabilized). We also see that, for the winter of 1990-1991, 150 MWh were recovered from the storage in a 3 month period. The thermal capacity of the storage is expected to be around 15 MWh/K (20'000 m^3 x 2.7 MJ/m^3K). When the operation of the storage started, losses were negligible and the initial slope of the curve on Fig. 3b corresponds to the inverse of the thermal capacity of the storage. Then we find 14 MWh/K in good agreement with the expected value.

Let us further mention that the observed storage losses are higher than what should be in normal conditions for two reasons: the average temperature of the ground around the storage is not yet stabilized at its final value (which will take a few years) and, due to the heat pump failures, the storage temperature went higher than expected. All these aspects are still to be carefully investigated during the coming years.

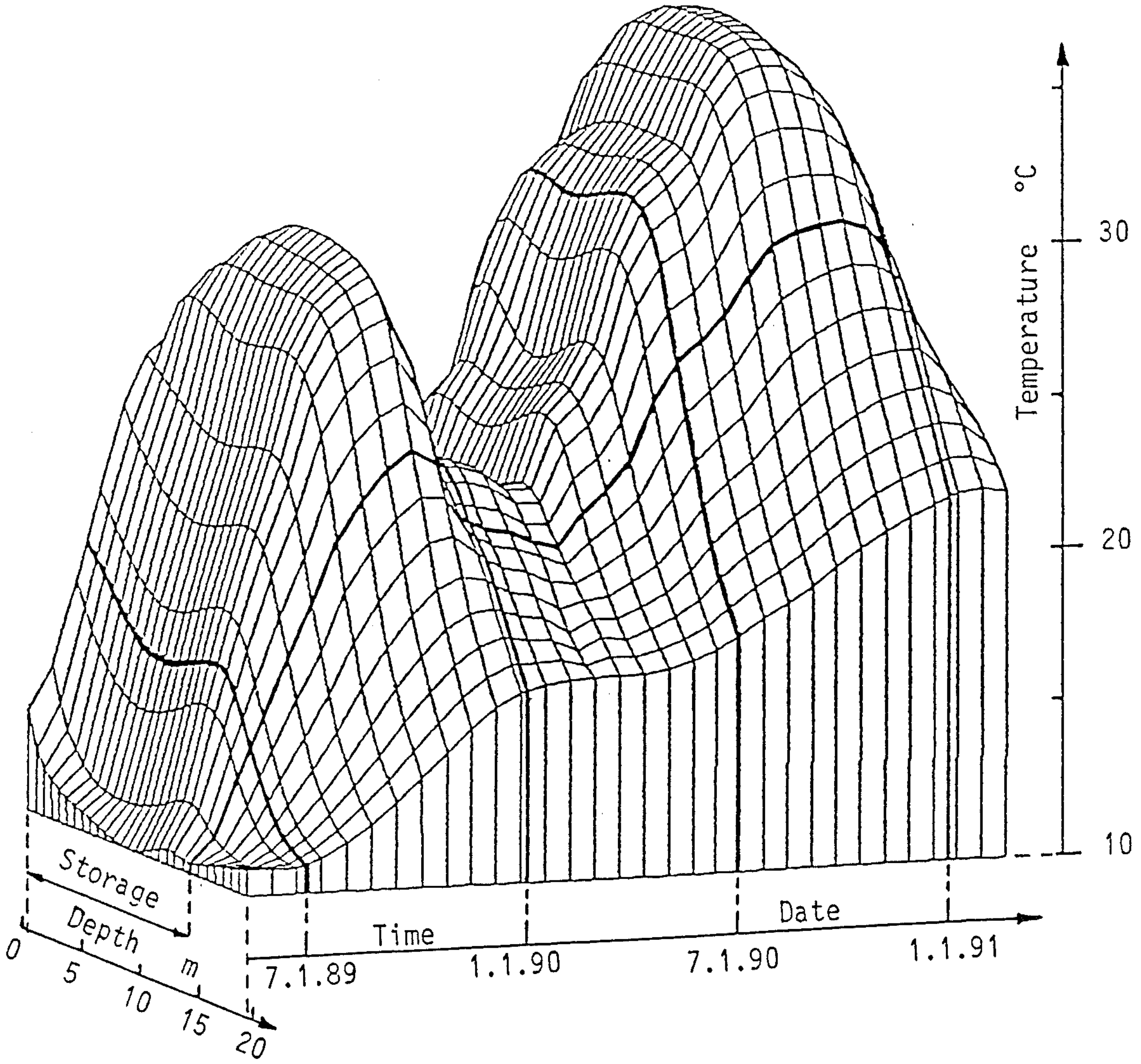

Fig. 1. Temperature of well 2 versus depth and time.

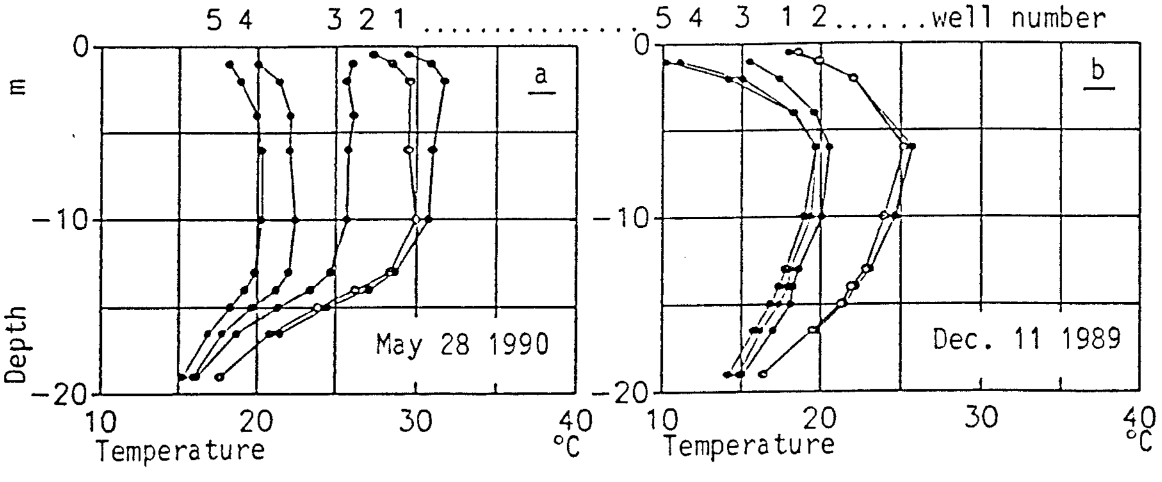

Fig. 2. Temperature profiles of the 5 monitored wells at given dates.

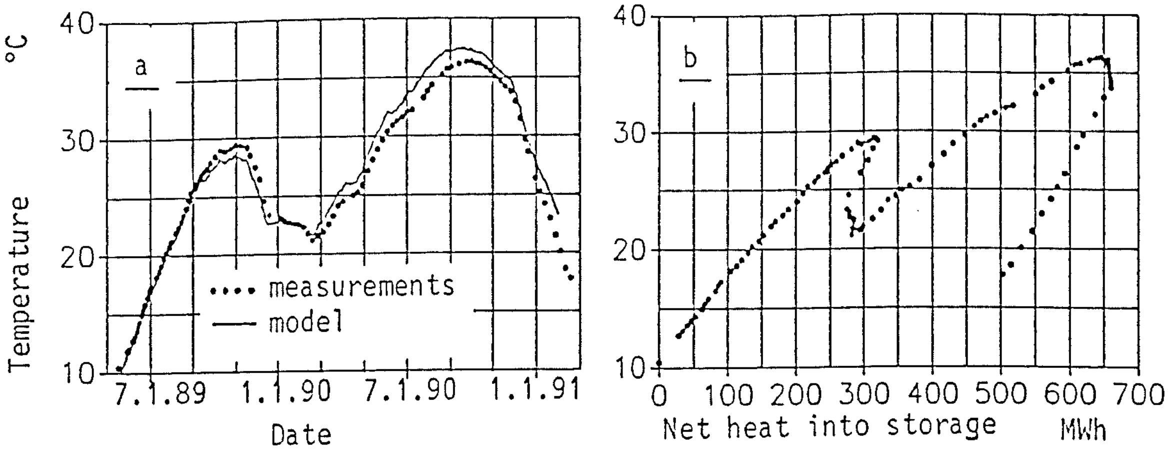

Fig. 3. Storage temperature versus time and versus injected heat.

MODEL

The purpose of modeling the underground storage is to describe reasonably well, and consequently to be able to predict and to optimize, temperature behaviours (versus space and time) and energy flows.

We first developed the *one cell model*. We consider one vertical heat exchanger and its surrounding ground as a cylindrical cell. We solve analytically the heat diffusion equation along one dimension, the radius, by means of Bessel functions. For instance, we define initial conditions, we give the heat flow injected inside the cylinder, we assume no external losses from the cylinder and we then compute temperature distributions. This model was developed and described in detail by Pahud (1989). It works rather well for cells in the middle part of the storage.

We now consider the ground surrounding the storage as a second larger cell (also cylindrical) and we consider the external temperature of the single cells as the internal temperature of this larger cell. Then we can compute, using the same routine as for single cells, the heat flow entering this large cell, that is, the lateral heat losses of the storage. We call this procedure the *double cell model*. We account for the losses below the storage by increasing correspondingly the lateral area of the storage. We may now correct the heat flow injected in the single cells for the external losses and iterate the process. We still evaluate the losses at the upper surface of the storage as usual conductive losses. Finally, by knowing the heat injected in and extracted from the storage, we can evaluate the temperature evolution of the storage and its losses.

The validation of such a model is illustrated on Fig. 3a. It has to be considered as a first attempt. Many points have still to be investigated and clarified in greater detail. But as a first try, it is very encouraging and satisfactory.

CONCLUSION

Our measurements show that the solar collectors, the gas powered heat pump and the underground storage behave as expected.

A simple modeling of the storage, based on the analytical solution of the heat diffusion equation, in case of cylindrical geometry, gives satisfactory results.

ACKNOWLEDGMENTS

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