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Heating and cooling by geothermal energy: Canadian well-Case of Rabat-

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Abstract
The demand on energy is growing driven by the industrial and socioeconomic development in many developing countries such as Morocco. Conventional fossil energies are pollutant and will eventually disappear in few decades. Therefore, renewable energies represent a good alternative because they are economical, permanently available and environmentally friendly. Geothermal energy is a renewable energy that consists in extracting the heat stored in the ground, to be used for heating in cold seasons and cooling in hot seasons. The Canadian or Provencal well is a geothermal system that uses the energy present in the ground, near its surface, to heat or cool the fresh ventilation air inside buildings. This study focuses on a Canadian well, which was set in a villa under construction in Hay Riad (Rabat, Morocco). The model representing the variation in soil temperature depending on the ambient temperature has been validated and allowed us to set the optimum depth for the installation of the Canadian well (2 meters in this case). Blowing trials have evaluated the performance of the system throughout the seasons. The power supplied by the Canadian well is higher in winter than in summer. The performance of the well varies depending on the nature of the soil, the rate of aeration and moisture, weather conditions, the air flow speed in the pipes etc. The energy balance concluded that the Canadian well is well suited to the city of Rabat that is based on a favorable groundwater.

Key-words: Canadian well, Soil temperature, Cooling, Heating, Energetic performance.

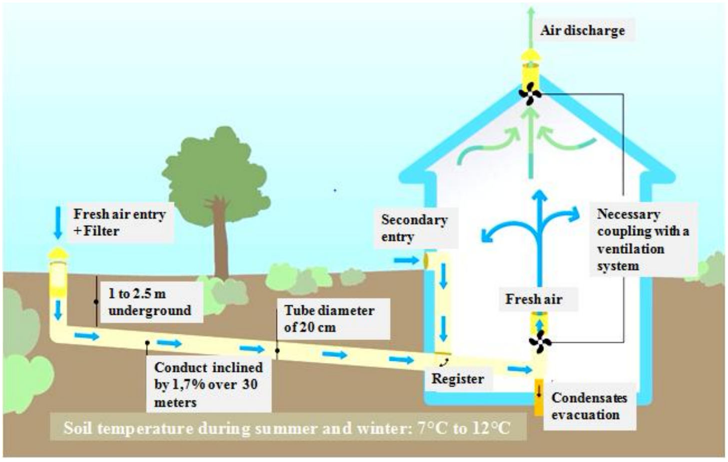
1. Introduction
Maintaining a comfortable temperature in a building may require a significant amount of energy. Independent heating and cooling systems are most often used to maintain this temperature, using a source of energy which is usually electricity, fossil fuel or biomass energy.

Compared to other energies that need to be transported over long distances, the ground energy has the advantage of being available on site and in large quantities. Because the land transfers heat gradually and has a large heat storage capacity, the temperature of the soil changes slowly, to the order of months or even years, depending on the depth of the measurement. Therefore, because of its low thermal conductivity soil may transfer part of the heat stored during summer to the winter season.
This annual and perpetual cycle of exchange between air and soil temperatures generates a heat exchange potential that can be exploited to heat or cool the building.
The concept of Canadian wells allows, in principle, to meet both requests: A flow of air is injected into the building from the outside; the air is previously forced through a registry of underground pipes (or equivalent system) and the inertia of the soil is used as a seasonal damper.
If we look closer, the tension between climate constraints and comfort thresholds induces, however, a fundamental asymmetry between potential preheating and cooling, using the ground as a buffer stock.
Thus, preheating the air (winter increase of ventilation temperature) will reduce energy consumption, which limits its potential by minimizing the air flow. While in summer, refreshment, by sinking below the comfort level of the oscillation day / night, can on the contrary be increased by raising the air flow rate (virtually "to infinity" since it is an open system).
The principle is the following: In winter, the ventilation air passes through a buried pipe. During its time pass, the air will warm up and allow a heating economy (known as "Canadian wells"). In summer, the same device will reload the hygienic air (known as "Provencal wells"), making real savings and allowing very good ventilation of the house [2].The Canadian well is intended to warm the fresh air in the winter and the Provencal well to cool it in summer. This thermal solution is called passive; it is then interesting to be studied, as part of an

environmental approach [8]. The various calculations of the evolution of soil temperature at several levels and the blowing trials inside the building perfectly illustrate the benefits that can be derived from modelling the Canadian well [3, 4].
A site was found (villa located in Hay Riad), where the owner agreed to install equipment and carry out work in his house under construction. The work consists in the installation of an entire air distribution system inside the house and excavations at the garden. These excavations took form of trenches 2.5 m deep and 40 m long. Once the work completed, we conducted a series of experiments, and in order not to deteriorate the air quality by its passage in the well, we created a slope of 2% minimum leading to a cesspool for the discharge of condensates and provided filters (G3 class filters, Final pressure drop of 250 pa) to prevent the entry of insects and pollen. We made sure to capture good quality air.
We preferred to take the air in the back of garden, from the water well. We designed a Canadian well with 80% efficiency (the heating in the well reaches 80% of the difference in temperature between the ground and the air outside), while not generating additional consumption for ventilation.

2. Materials and methods

A Canadian well was built in a villa in Hay Riad (Rabat), under construction. The laying of the pipeline was completed in June 2010 on trenches of 70 cm wide and 2.50m maximum depth. The canalizations used are made of PVC pipes 20 cm in diameter and 6 meters in length and rely on a sand bed of 20 cm.
The embankment was carried out using the excavated land cuttings, screened by a masonry screen.
The total length of the pipe is 30 meters. It starts from the water well constructed in the garden to finish at the building entrance (side Moroccan lounge ground floor). At the deepest point (- 2.50 m) a siphon was placed to drain condensation water which may occur at the level of the pipe. Below the drain, a dry well was carried out using rubble. In fact, during the cooling of external air and once in the pipe, condensation will take place according to the humidity.
This phenomenon occurs especially in summer because hot air stores more humidity than the same volume of cold air. It is therefore necessary during the excavation to pay attention that the slope (1to 3%) is in the same direction as the flow, and provide absolutely smooth pipes**.**
All of the pipe results in a metal box of 0.7 x 0.7 x 0.7 m. this box is manufactured by galvanized sheet metal and insulated by glass wool (sandwich panels). Inside the box a suction fan 100 W equipped with a switch is placed. The box output has two openings: one going to the ground floor and the other to the first floor of the villa.
The air blown by the fan is circulated through pipes of corrugated aluminum of 100 mm diameter**.** The air inlet must be located away from sources of pollution (roads, parking, trash ...) and high enough to avoid breathing dust. The figure below presents a synoptic scheme of the system used:



Source: Diagram of operation of a climate well © ADEME-2012

2.1. Soil temperature

During the month of June 2010, we recorded the temperature of the soil at various depths. The results are gathered in the figure 1. The tests were carried out in the week from 24/04/2009 to 02/05/2009. Temperatures were recorded every 5 minutes.

The results show an evolution in saw tooth for soil temperatures and that of the atmosphere.

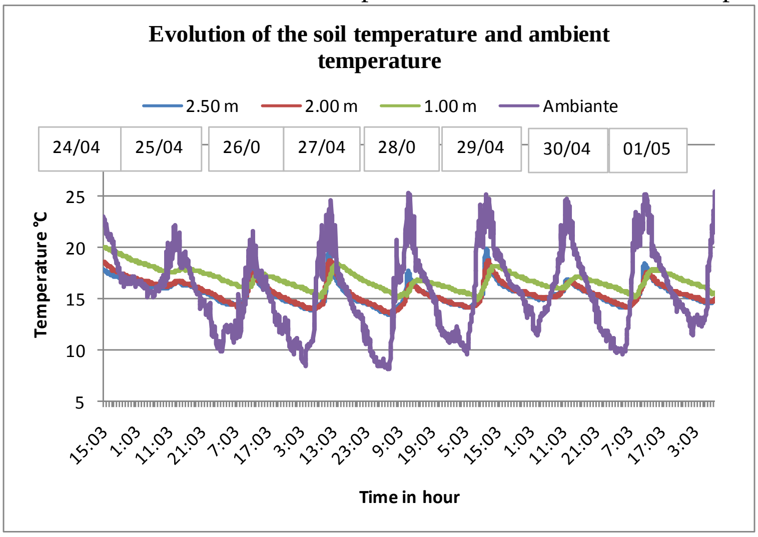


Figure 1: The evolution of soil temperature during one week of may 2009

Soil temperature is more stable than that of the atmosphere. From 2.00 m, there is no significant temperature variation. A depth of 2.00 m for the Canadian wells is then considered to be sufficient. These temperatures have the characteristics summarized in the table 1:

Table 1: Soil temperature and the atmosphere temperature in °C

Temperature	Minimum	Maximum	Average	Amplitude
Ambient Temperature	8.1	25.5	15.5	17.4
Temperature at -1,00 m	14.9	19.9	16.7	5
Temperature at -2,00 m	13.6	18.8	15.5	5.2
Temperature at -2,50 m	13.5	18.4	15.5	4.9

2.2. Modeling Thermal structure of the soil model

The floor model considered here has been widely used in the literature (Mihalakakou et al, 1977. Benkert et al, 1997.) . It quite simply is to consider the soil as a semi- infinite solid, surface excited by a sinusoidal signal temperature. In fact, in this model the solutions are sinusoidal as well with the same period and pulsation as the temperature signal but whose phase and amplitudes vary with the depth considered. Overall, the greater the depth, the greater the sinusoidal signal is muted and delayed. The analytical solution of this Model is established.

The propagation model of heat conduction in a semi-infinite solid proposes an analytical solution when the surface temperature of the solid is sinusoidal. Accordingly, all the stresses of the problem must be reduced to constant or sinusoidal functions of time.

The outside air temperature, T_{air} will be conveniently expressed:

$$T_{air}(t) = m + A\sin(\omega t - \varphi) \qquad (1)$$

m: mean period temperature [°C].
A: amplitude of the temperature variation [°C].
ω : Pulsation. [rad/s].
φ : Phase shift [rad].

By fitting equation (1) with the experimental results, we obtain the following values:

m: mean period temperature =16 °C.
A: amplitude of the temperature variation =7.9 °C
ω : Pulsation= $4.42254.10^{-3}$ rad/s.
φ : Phase shift = - 1.61479rad.

Equation (1) becomes

$$T_{air}(t) = 16 + 7.9 \sin\left(4.42254.10^{-3}t - (-1.61479)\right) \quad (2)$$

The results of this simulation are shown in the figure 2 below.

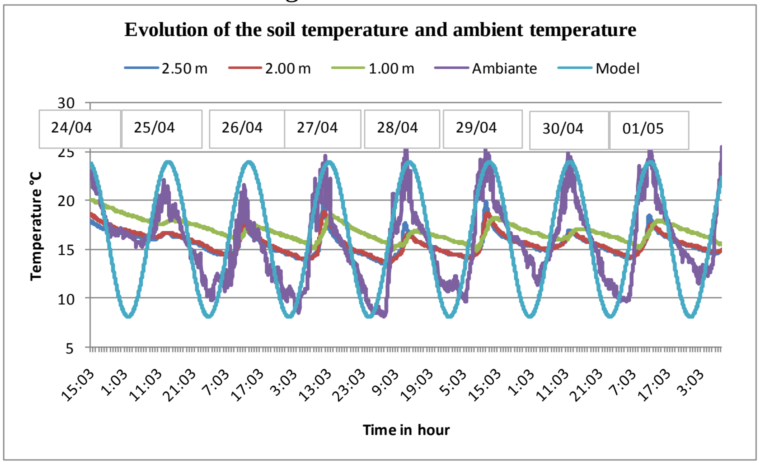


Figure 2: Simulation of the soil temperature and ambient temperature

By solving the heat equation for a transient semi-infinite environment whose surface temperature is imposed by equation (1) we obtain the soil temperature function of depth(x)

$$T_{soil}(x,t) = m + Ae^{-x\sqrt{\frac{\omega}{2\alpha}}} sin\left(\omega t - \varphi - x\sqrt{\frac{\omega}{2\alpha}}\right) \quad (3)$$

With

- α: thermal diffusivity (k / ρ.C)
- k: thermal conductivity en W / (m.K)
- ρ: density of soil in kg/m^3
- C: specific heat capacity of the soil in J / (kg.K)

The simulation results are shown below (Figure 3):

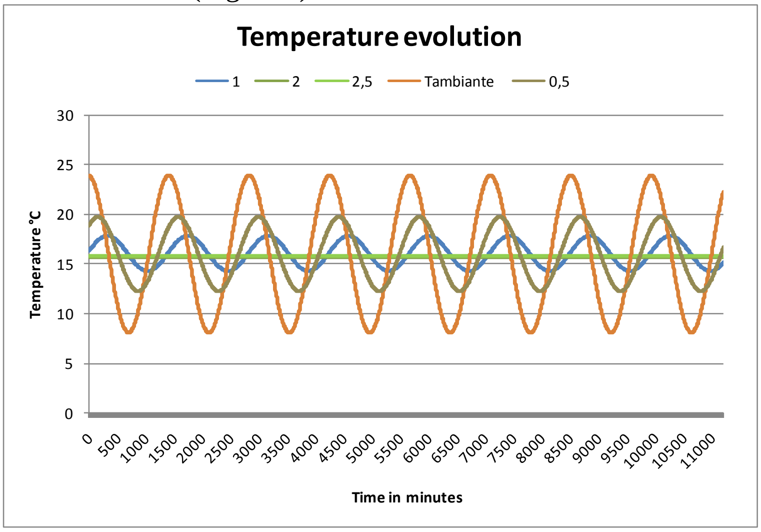


Figure 3: Simulation of soil temperature

Soil temperature follows a sinusoidal variation. It is found that the temperature penetration in the ground decreases with depth which is in perfect agreement with the logic as the attenuations are much larger gradually as the depth increases (temperature variations are much lower than the depth of the system is important). In these conditions, the depth to be used in our study is 2 meters.

The simulation results are shown below:

3. Blowing tests

Blowing tests were performed for several days to determine temperature profiles at various locations:

- Ambient Temperature.
- Inlet temperature of the Canadian well.
- Temperature in the chamber (outlet Canadian well).

3.1. Test N°1: Winter

The first test was conducted during two days of December 2011(03 and 04 December). Temperature and difference temperature profiles are shown in figures below:

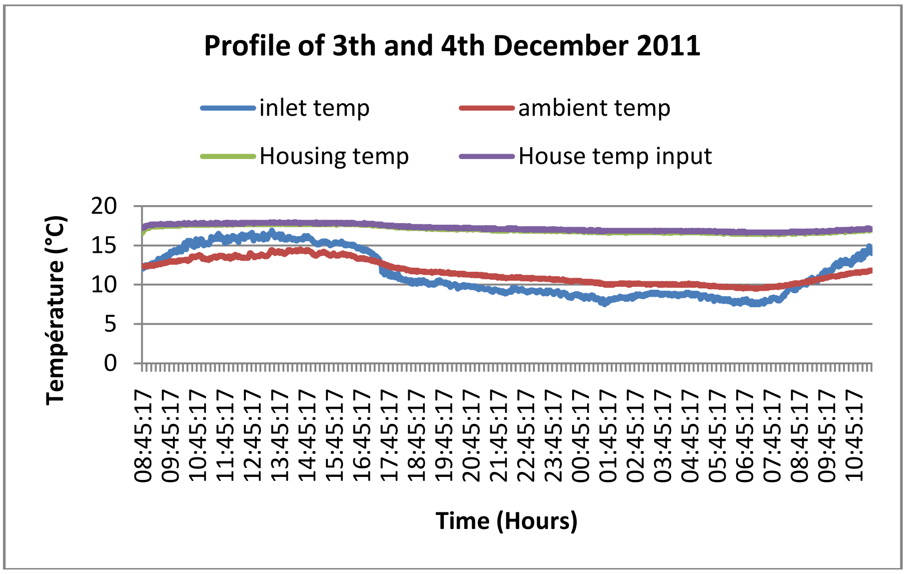


Figure 4: Profile of 03 and 04 December 2011

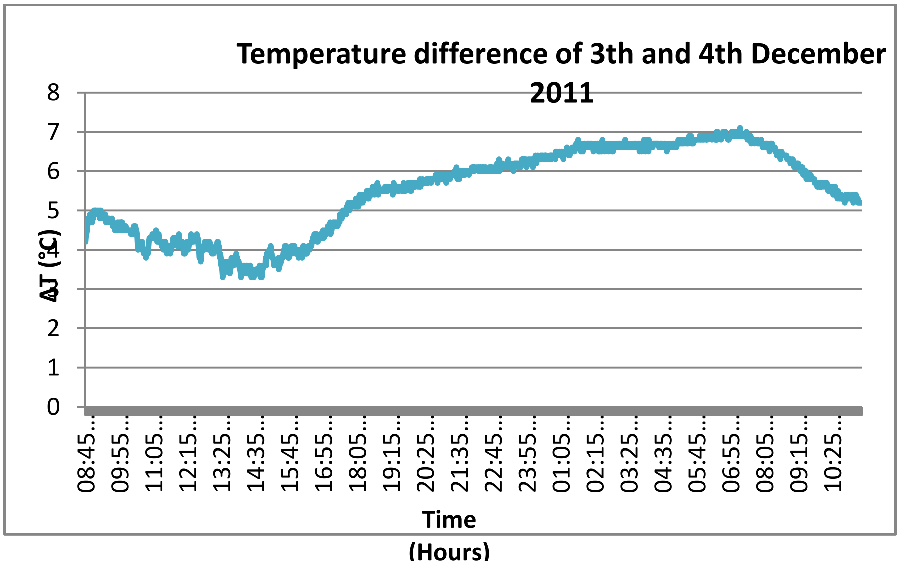


Figure 5: Temperature difference (03 and 04 December 2011)

We notice that the ambient temperature fluctuates with an amplitude peak to peak of 8.5 °C with an average of 11.6 °C while blowing air into the house fluctuates with an amplitude of 1.5 °C and an average of 17.1 °C.
The temperature difference between ambient air and air blown varies from 3.4 °C to 7 °C. The minimum is reached during the day at 14h00 while the maximum is reached during the night at 19h00 (see figure below).

3.2. Test N°2

The second test was conducted during two days of January 2012(31January and 01 February). Temperature and difference temperature profiles are shown in figures below.

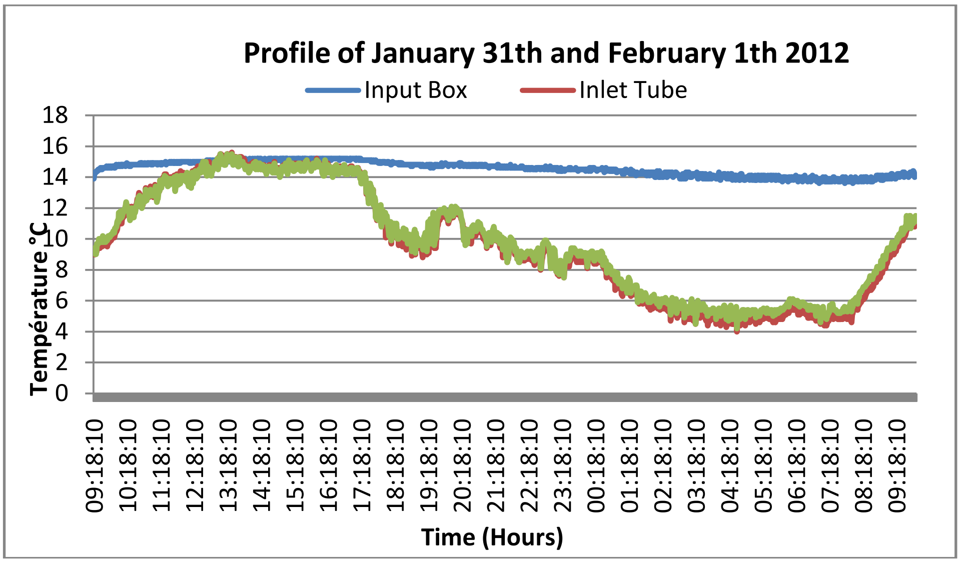


Figure 6: Profile of 31 January 2012 and 1 February 2012

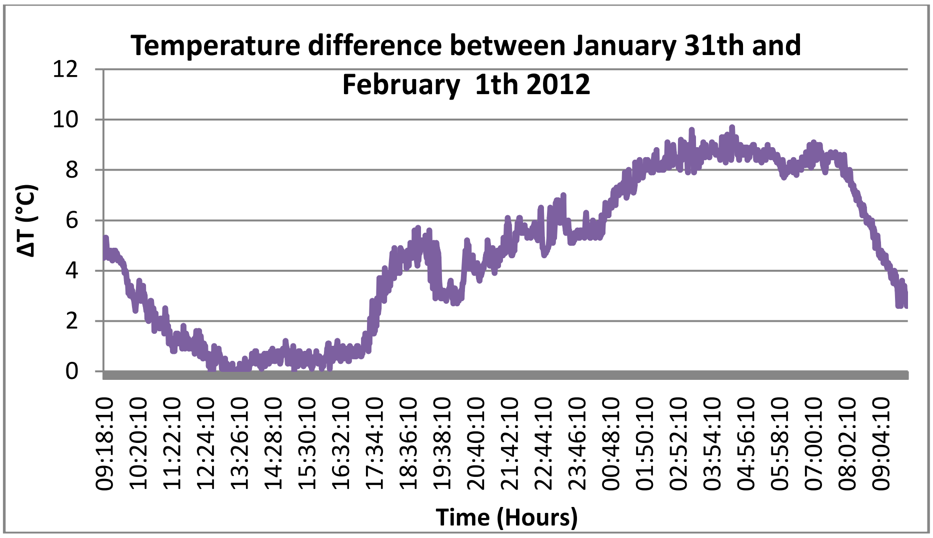


Figure 7: Temperature difference (31 January and 01 February 2012).

We notice that the ambient temperature fluctuates with peak to peak amplitude of 11 °C with an average of 9.9 °C while blowing air into the house fluctuates with amplitude of 1.0 °C and a average of 14 °C.
The temperature difference between ambient air and air blown varies from 0 °Cto 10 °C. The minimum is reached during the day at 13.10 while the maximum is reached during the night to 5am (Figure 7)

3.3. Test N°3

The third test was conducted for six days of February 2012 (from February 5th to February 11th). Temperature profiles are shown in the figures below.
We noticed that the ambient temperature fluctuates with peak to peak amplitude of 12.5 °C with an average of 8.9 °C while blowing air into the house fluctuates with amplitude of 1.5 °C and an average of 13.8 °C.
The temperature difference between ambient air and air blown ΔT varies from 0 °C to 11 °C. The minimum is reached during the day at 13h while the maximum is reached at night between 3h and 4 h (Figure 9).

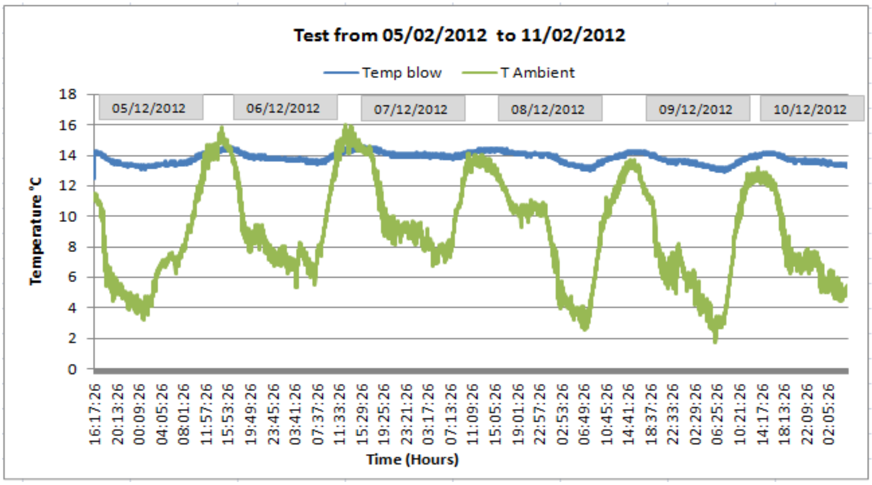


Figure 8: Temperature profile (from 05/02 to 11/02/2012)

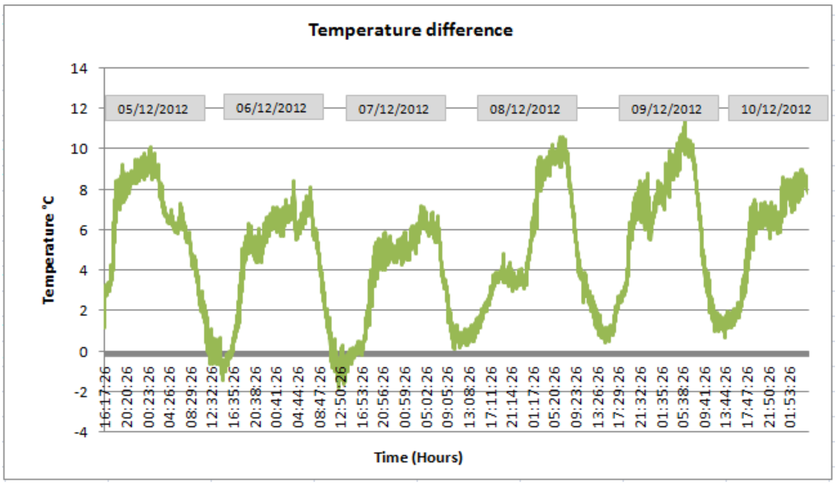


Figure 9: Temperature difference (from 05/02 to 11/02/2012)

3.4. Test N°4: Spring

The fourth test was conducted for two days of April (26 and 27 April) 2012. The temperature and difference temperature profiles are shown in the figures below.

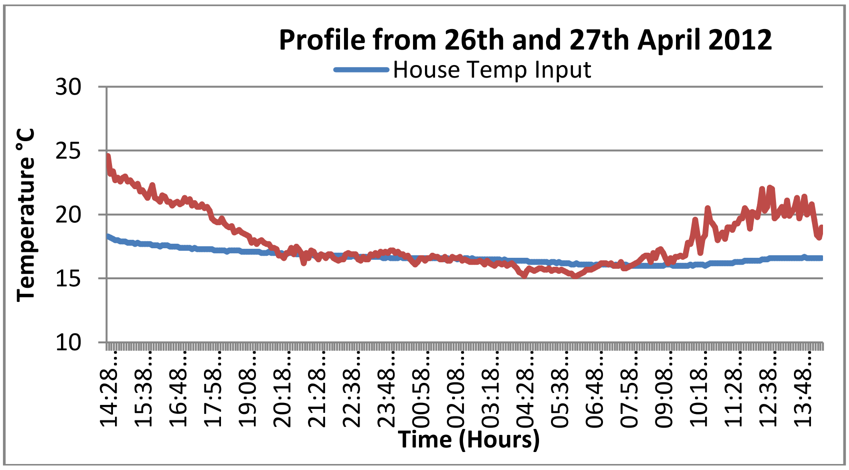


Figure 10: Profile of 26 and 27 April 2012

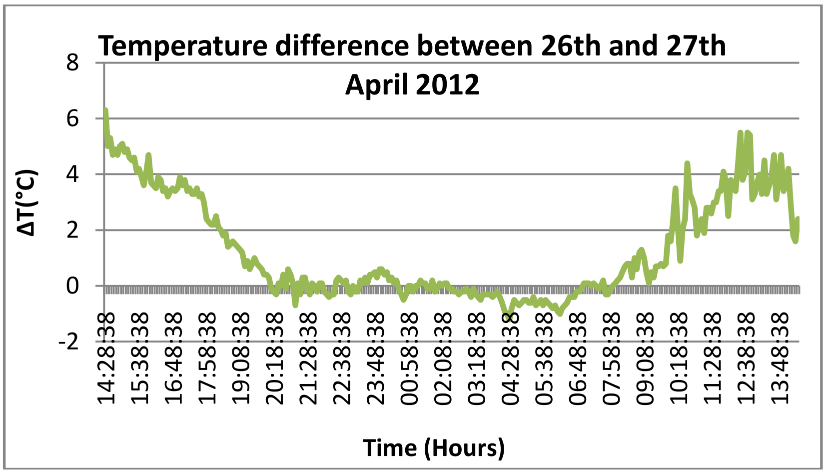


Figure 11: Temperature difference (from 26/04 to 27/04/2012)

These records the ambient temperature fluctuates with a peak to peak amplitude of 10 °C while blowing air into the house fluctuates with an amplitude of 2 °C and an average of 15.5 °C. It is noticed after the temperature difference between ambient air and the supply air varies from -1 °C to 5.2 °C. The minimum is reached overnight at 5h while the maximum is reached during the day between 13 and 14 h (Figure 11).

3.5. Test N°5: Summer

The fifth test was conducted for four days of August 2013(from 13 to 16 August). Temperature and difference temperature profiles are shown in the figures below:

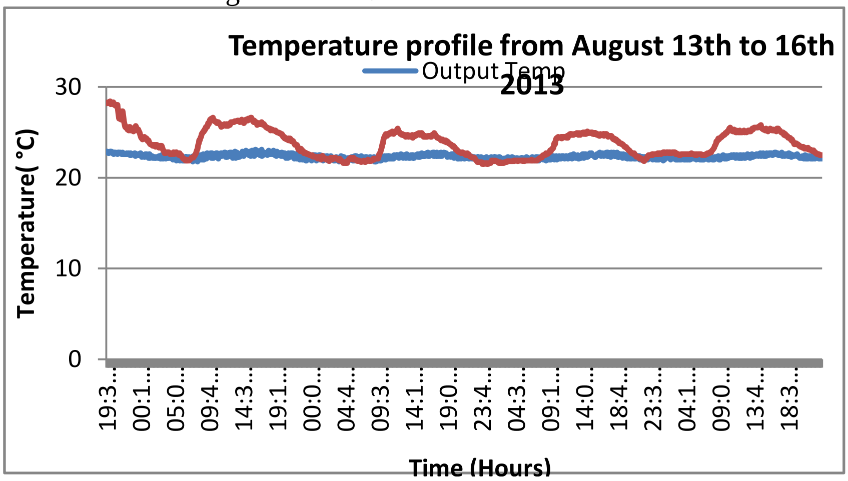


Figure 12: Temperature profile (from 13/08/2012 to 16/08/2012)

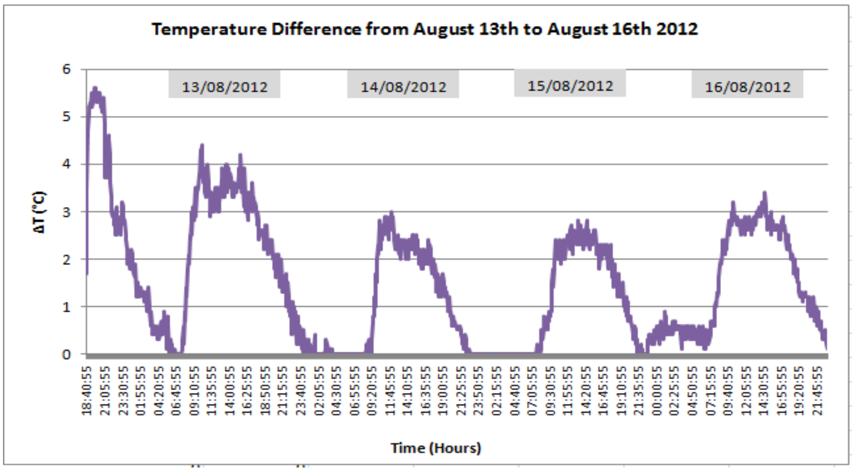


Figure 13: Temperature difference (from 13/08 to 16/08/2012)

We notice that the ambient temperature fluctuates with a peak to peak amplitude of 7 °C with an average of 3.6 °C while blowing air into the house fluctuates with an amplitude of 5.4 °C and a average of 1.64 °C.
The temperature difference between ambient air and air blown varies from 0 to 8 °C. The minimum is reached during the day at 06 h while the maximum is reached at day between 15 and 16 h (Figure 13).
From these tests we may make the following conclusions:

For the winter season:

• The winter season can always gain energy and this 24h/24.
• The difference in temperature between the ambient air and the blowing air is between 0 and 11 °C.

For the spring season:

• The spring season provides an energy gain only during the day and this between 7h and 18h.
• The temperature difference between ambient air and the blowing air is between 0 and 5 °C.

For the summer season:

• The summer season can always gain energy and this 24h/24.
• The difference in temperature between the ambient air and the blowing air is between 0 and 8 °C.

4. Thermal Input

3.1. Calculations

The calculation of a Canadian well is a function of several parameters. The main parameters include:

1. The volume of the house
2. The flow needed in winter and summer
3. The choice of ventilation in the house (VMC, natural ventilation,)
4. Architecture (bioclimatic, materials, insulation, greenhouse,)
5. The nature of the soil (sand, clay, water table,)
6. The space available for the burial of the pipe
7. The geographic location
8. The budget

3.2. Assumptions

This is a conventional masonry house with healthy materials, where the insulation has been strengthened. To explore the site, we started from a soil survey, local climate and the volume of air to be renewed, the soil is clay, which is particularly suitable for installation. The climate in Rabat is mild in winter; it's mostly in summer that the gain in comfort will be visible.

3.3. Three modes of operation

- *Winter:* The objective is to warm the air before it enters the house. To get the maximum heat exchange, air must travel at a speed of 2.3 m / s.
- *Summer:* The goal is to freshen up the house in case of high heat. The bioclimatic house was designed to handle a maximum passive intake from the sun by the windows and thus create shaded areas to avoid substantial heat input during the day (awning, plantation in south ...). The Canadian wells shall be supplemental to these measures. For maximum efficiency, the air flow will be more important to renew the whole house air every 2 hours.
- *Offseason*: The comfort temperature is between 18 °C and 22 °C, and the system will be disconnected by a branch if necessary, to not cool the house when the outside temperature is close to the comfort temperature.

3.4. Constants:

1. Volume of the house 800 m^3
2. Temperature set point 20 °C
3. Temperature of the bypass 18 °C and 25 °C
4. 1 pipe 30 m PVC diameter of 200 mm (Int) to average depth 1.5m

To calculate the total pressure loss in the air circuit, we must add up the pressure loss in each element of the circuit. Blowing tests were carried out with centrifugal fan (Canal ‘air Type C160) whose characteristics are summarized below:

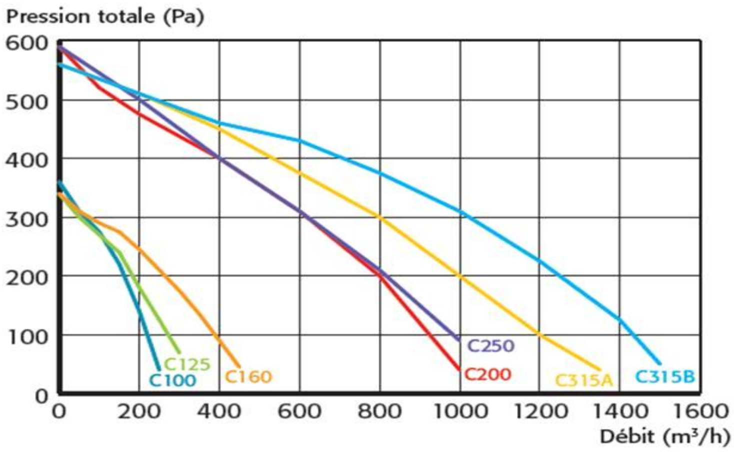


Figure 14: Flow of the fan in function of the pressure

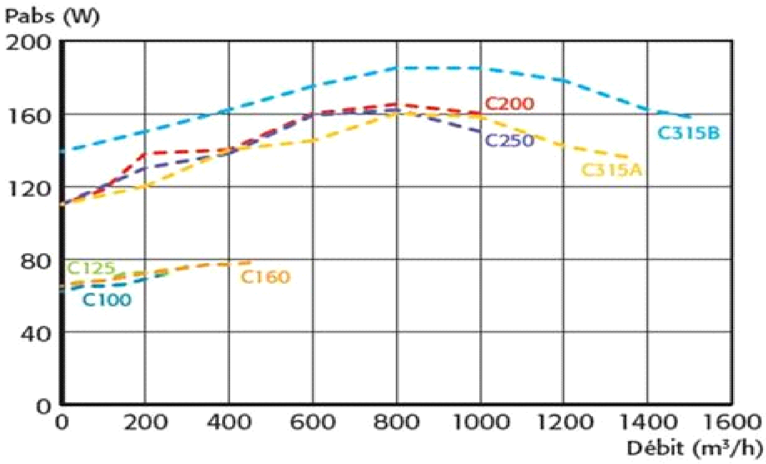


Figure 15: Fan consumption curves

The flow rate within the conduit (Canadian tube) was constant throughout the duration of the measurements and it would be interesting to make it vary depending on the season with a dimmer for example.
The results of blowing trials for four different time periods are shown in the following figures. The air velocity in the Canadian wells was 2.3 m/s corresponding to an average flow of 260 m^3/h.

Flow = velocity x duct Section

$$Flow(m^3/h) = 2.3(m/s) \times 3.14 \times (0.2)^2/4 \times 3600 = 260(m^3/h)$$

The Canadian wells' power varies between 0 and 1 kW depending on the season. The net savings (deducting consumption of the fan) vary between 2 kWh/month (summer) and 258 kWh/month (winter)

Table 2: Canadian wells Powers

Period	Mode	Power interval in kW	average power in kW	Energy wells kWh / month	Fan kWh / month	Economy kWh/month
From 3 to 4 December 2011	heating	0.3 – 0.6	0.48	344	86.4	258
From January 31 to 2 February 2012	heating	0 – 0.8	0.41	293	86.4	206
From 05 February to 11 February 2012	heating	0 – 1.0	0.42	306	86.4	219
From 26 April to 27 April 2012	Cooling	0 – 0.5	0.12	89	86.4	2
From 13 to 16 August 2012	Cooling	0 – 0.7	0.16	113	86.4	26

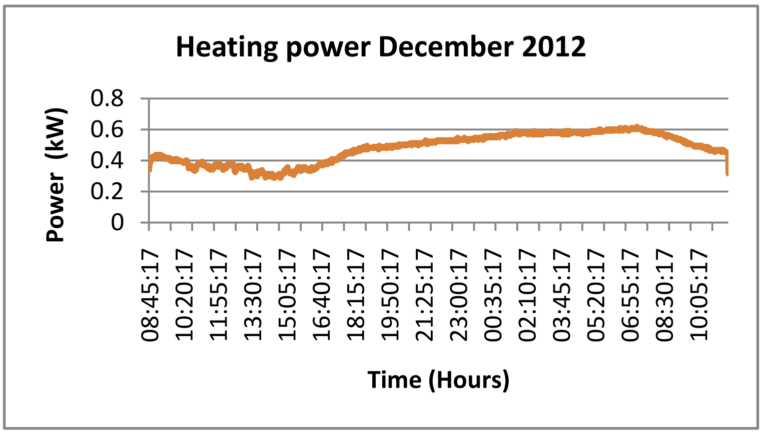


Figure 16: Evolution of the heating power (December 2012)

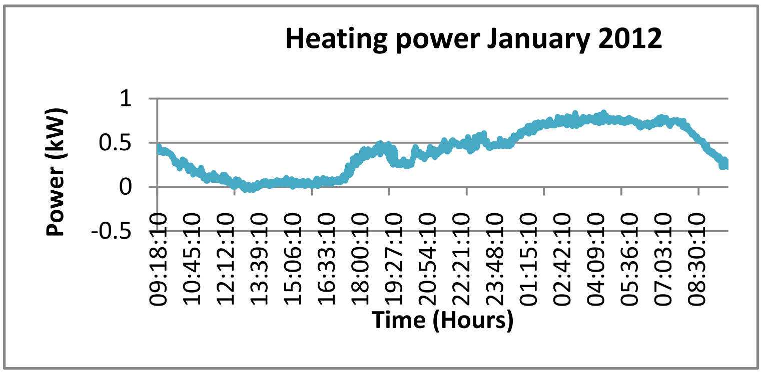


Figure 17: Evolution of the heating power (January 2012)

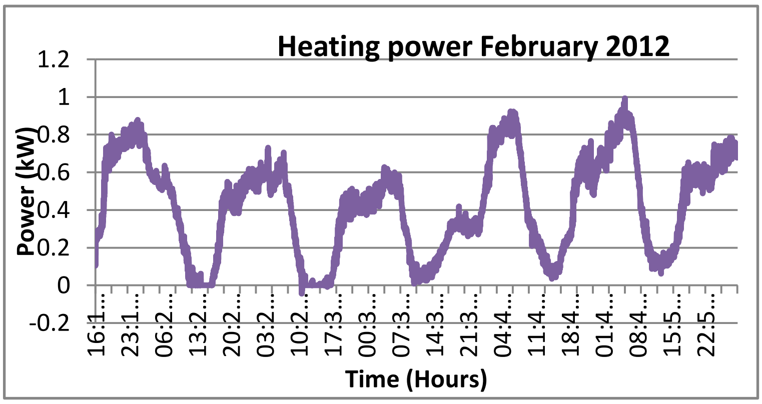


Figure 18: Evolution of the heating power in February 2012

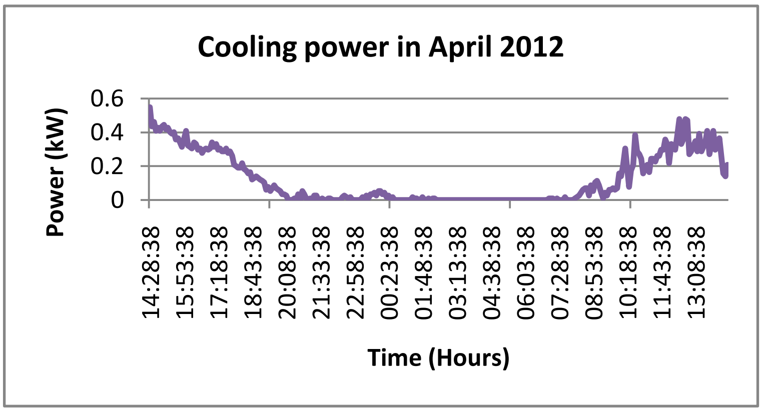


Figure 19: Air Power (April 2012)

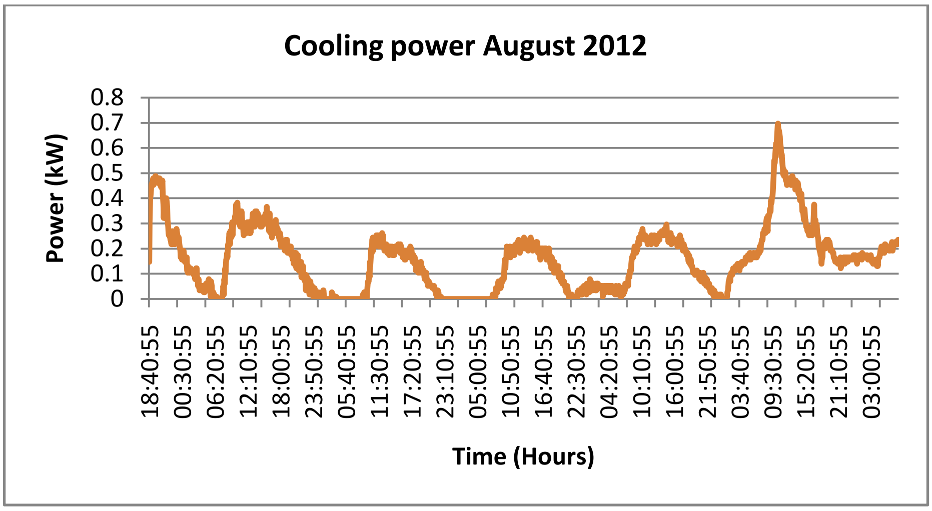


Figure 20. Air Power (August 2012**)**

The Canadian well performance coefficient ranges from 0 to 5.8 depending on the season with an average coefficient of performance up to 4 in winter as shown in the table below:

Table 3: Canadian well coefficient of performance

Period	Power interval kW	Fan power kW	Coefficient of performance COP	COP Average
From 3 to 4 December 2011	0.3 – 0.6	0.12	2.5 - 5	4.0
From Jan 31 to Febr 2, 2012	0 – 0.8	0.12	0 – 6.7	3.4
From 05 Feb to 11 Febr 2012	0 – 1.0	0.12	0 -8.3	3.5
From 26 April to 27 April 2012	0 – 0.5	0.12	0 – 4.2	1.0
From 13 to 16 August 2012	0 – 0.7	0.12	0 – 5.8	1.3

Conclusions

According to experiences performed on the Canadian well (Rabat site), we can make the following conclusions:

1. The model representing the variation in soil temperature has been validated and allowed to set the optimum depth for the installation of a Canadian well (2 meters for the site of Rabat). The chosen model has the following form and predicts soil temperature with sufficient accuracy

$$T_{soil}(x,t) = m + Ae^{-x\sqrt{\frac{\omega}{2\alpha}}} sin\left(\omega t - \varphi - x\sqrt{\frac{\omega}{2\alpha}}\right)$$

2. Blowing trials have evaluated the performance of the Canadian well for three seasons (Winter, Spring and Summer). The power supplied by the Canadian well is more important in winter than in summer.
3. The coefficient of performance is variable and can reach a snapshot of COP 8.3 in winter with an average of 4.
4. The performance of the well will vary depending on the nature of the soil: its rate of aeration and moisture, weather conditions, the air flow speed in the pipes etc.
5. As a general conclusion, it can be argued that four levers exist to improve summer comfort in the building: sun protection, control of internal gains, inertia and ventilation.
6. The Canadian or Provencal well is called a passive thermal solution, which is installed upstream of the ventilation system, and which uses the thermal inertia of the ground to preheat or cool the air inside the building. It is therefore of great interest for buildings that have no inertia.

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