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Diminishing Energy Consumption in Heating and Cooling Passive Houses Using Geothermal Energy

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Abstract

The paper is divided into five parts. In the first the importance of increasing the energy performance of buildings is set into evidence under the circumstances in which the buildings are responsible for a considerable input as considering both energy consumption and green house effects emissions. In view of meeting the objectives of energetic policies the emphasis will be set on the passive house standards and its advantages as significant energy consumption is concerned. In the second section the paper presents the system of exploiting the shallow thermal potential of earth, by using earth – air heat exchangers also known as Canadian wells. In the third section, the mathematic model is presented that is laying at the basis of Canadian wells systems analysis, in dynamic system with simulating soft. In the fourth part the results of Canadian wells system analysis are presented and in the fifth part the paper comes up with the conclusions referring to the influences of various parameters upon improving the performances of these systems.

Rezumat

Lucrarea este împărțită în cinci părți. În prima parte este evidențiată importanța creșterii performanței energetice a clădirilor, în condițiile în care clădirile sunt răspunzătoare de un aport considerabil în ceea ce privește atât consumul energetic cât și emisiile de gaze cu efect de seră. În vederea îndeplinirii obiectivelor politicilor energetice se va pune accent pe standardul de casă pasivă și avantajele sale în privința reducerii însemnate a consumurilor energetice. În partea a doua se prezintă sistemul de valorificare a potențialului termic al solului de adîncimi mici, respectiv sistemul de tip puț canadian. În partea a treia se prezintă modelul matematic ce stă la baza analizei sistemelor de puțuri canadiene în sistem dinamic, cu soft de simulare. În partea a patra sunt prezentate rezultatele analizei sistemelor de puțuri canadiene iar în partea a cincea concluziile referitoare la influențele diverșilor parametrii asupra îmbunătățirii performanțelor acestor sisteme.

Keywords: energy performance, consumption, passive house, thermal potential, Canadian well.

1. Introduction

Taking into consideration the high proportion of total energetic consumption of buildings (40%) and greenhouse effects emissions (36%) the energy performance of buildings represent the key to

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attaining the target objectives of the European Union energetic policy namely: environmental protection by diminishing greenhouse effects emissions by 20% until 2020, improvement of energetic security by increasing energetic efficiency by 20% until 2020 and expanding the renewable sources of energy by 20% until 2020 [1].

In the field of the highest energetic efficiency and ecological constructions, the passive houses represent the top standards offering the solution to reducing energy consumption, along with improving the comforts, all these being promoted by the efficient use of the renewable sources of energy (solar and geothermal especially). The annual consumption of heating/cooling is limited to 15 KWh/ m^2 per year, and the total annual consumption of primary energy for heating, cooling, domestic hot water, illumination, electric appliances is restricted to 120 KWh/ m^2 annually [2].

The concept "passive house" was defined and coined by the Passivhaus Institute led by Dr Wolfgang Feist and has the following form: "A Passive House is a building, for which thermal comfort (ISO 7730) can be achieved solely by post heating or post cooling of the fresh air mass, which is required to fulfill sufficient indoor air quality conditions (DIN 1946) - without a need for recirculated air" [3].

Accomplishing the passive house is based upon the optimization of its components and minimizing losses [4]:

- compact structure surface/volume ratio between 1 and 0.2 for reducing losses towards exterior;
- an optimum orientation of building with most exposed surface towards the south to increase solar input in the cold season;
- a proper thermal insulation in view of heat losses to the exterior in cold seasons and of heat flow to the interior in the warm seasons; one recommends limiting the global coefficient of heat transfer below 0.15 W/ m^2K value at the level of opaque components and 0.8 W/ m^2K at the level of transparent components (windows);
- a proper sealing at the level of the whole envelope in view of avoiding air inflow, condensation and air losses to the exterior. A number of maximum hourly exchanges of 0.6 h^{-1} is recommended;
- heat recovery.

Due to a perfect insulation and tightness for providing thermal comfort and quality of inside air, will be necessary the implementation of a mechanically controlled double-flow ventilation system with heat recovery from the exhausted air (Fig. 1) [5].
The heat exchanger represents an air to air counter flow heat exchanger of high efficiency between 75 and 95%.

The mechanically controlled ventilation systems are usually employed in association with earth to air heat exchangers called Canadian wells [6]. The association of a Canadian well system with the mechanically controlled ventilation with heat recovery will provide higher temperatures in winter and lower in summer, leading this way to lowering energy consumption for heating and cooling the passive houses and thus to significant energy savings.

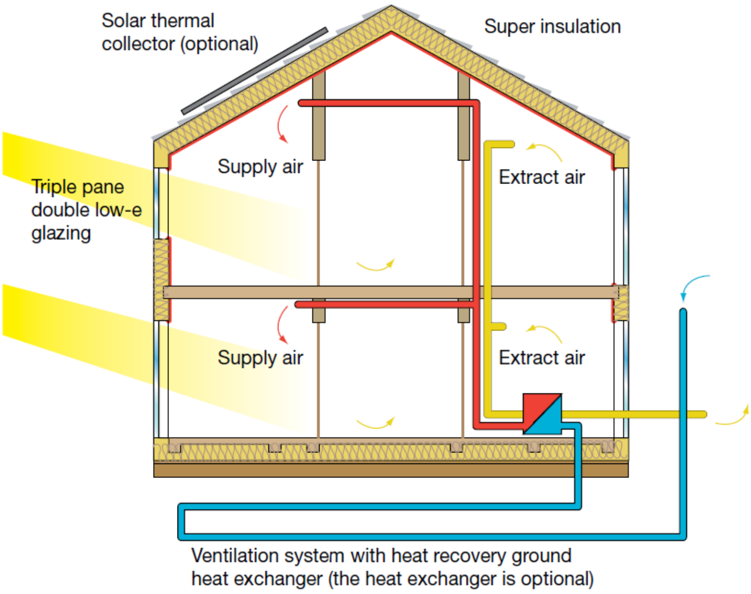


Figure 1. Equipping a passive house with air to air heat exchanger and Canadian well [5]

2. Enhancing of low depth geothermal energy

The Canadian wells employ geothermal energy- thermal energy stored in the earth at low depths [7] in view of providing the heating agent (air) for heating/cooling the passive houses.

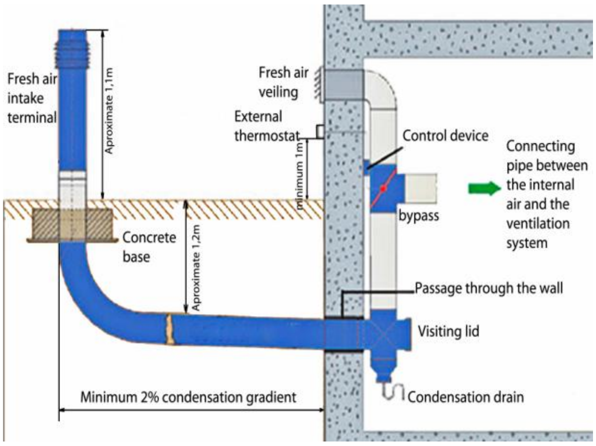
In the cold season, the Canadian wells will be used for preheating the external air before being put in the heat exchanger as a result of the heat exchange effected with the earth, which at a certain depth the temperature is higher than the air outside and the temperature fluctuations are lower. In warm seasons, the reverse will be the case, the Canadian wells will act for cooling the external air as a result of heat yielded to the earth being colder than the air outside.

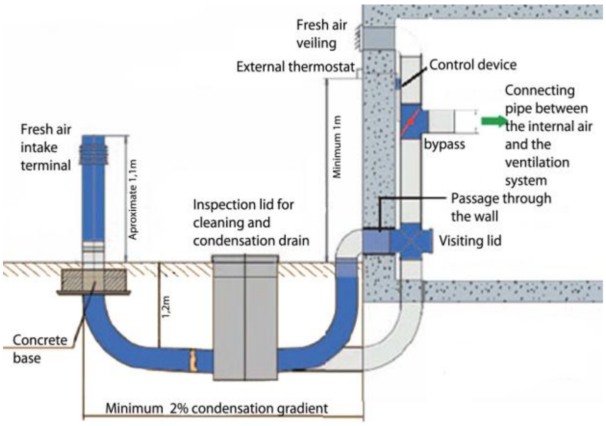
In the intermediate seasons when the outside air temperature nears the optimum, the Canadian wells will not function for avoiding the sensation of discomfort.

Constructively, the system of a Canadian well consists of the following elements [8]:

- external air intake, fitted with a grating and mechanical filters;
- buried pipe work with a mounting slope of about 2%;
- condensation drain;
- electrically operated by-pass choke valve (when the air temperature is between 18^{o}C and 22^{o}C);
- fresh air intake in bypass-at system;
- temperature sensor(thermostat);
- connection hose to a system of double-flow mechanically controlled ventilation with heat recovery.

A schematic diagram of a Canadian well type system is presented in Fig. 2.





a) building with basement

b) building without basement

Figure 2. Schematic diagram of a Canadian well [8]

In dimensioning the Canadian wells systems one should consider the following parameters: the necessary air flow rate, length of pipes, pipes diameter, the speed of air flow through pipes, characteristics of the soil, the mounting depth of pipes. The following recommendations are made [9]:

- the ratio between volume and lateral surface of pipe should be less than 6; for too large diameters (poor contact between air and the lateral surface of the pipe) the heat transfer would be too poor and the air would not get sufficiently hot/cold;
- the pipe should be as smooth as possible inside to avoid the increase of charge losses in the system;
- the pipe should be tight to avoid penetration of underground water and radon;
- the speed of air flow through pipes should be 1-2 m/s in winter and 3.5 m/s in summer (for an optimum heat transfer);
- on the external air intake one should mount air filters, oblique fix shutter frames (against rain, and grate against flotsam/stray objects).

3. Mathematic model presentation of Canadian wells

The analysis of these systems will be effected by means of GAEA Application developed by FB&S, Siegen University, Germany and offered for use to Prof.dr.eng. Heidl.

The mathematic model pursued in effecting the GAEA application was presented in the survey made by Heidl and Benkert and facilitated the following analyses [10]:

- the influences of the Canadian well (the earth to air heat exchanger) upon diminishing energy consumption in a passive house;
- determining the optimum geometric parameters of the Canadian well for providing a given air flow rate.

For starting the following information will be required: the distribution of external air temperature and distribution of earth temperature.

The temperature of external air will represent the temperature of the air entering the Canadian well. The annual variation of external air temperature will be determined in conformity with relation [10]:

$$\theta_a(t) = \theta_m + (\theta_{\max} - \theta_m)\cos\left(2\pi \frac{t}{t_0}\right) \tag{1}$$

where,

$\theta_a(t)$ – external air temperature at time t, [^{0}C];

θ_m – annual mean value of external air temperature, [^{0}C];

$\theta_{\max}$ – annual maximum value of external air temperature, [^{0}C];

t – time [s];

t_0 – duration of year [s] (31.5x10^6 s).

Besides the annual variation of earth temperature at a certain depth, the application also enables the determination of annual variation of air temperature along the Canadian well and the annual variations of soil temperature contacting it.

The variation of soil temperature at the contact with pipe wall, unaffected by it is calculated as a function of annual man temperature of the external air and its annual maximum value [10]:

$$\theta_s(t) = \theta_m + (\theta_{\max} - \theta_m) \cdot e^{-\zeta} \cdot \cos\left(2\pi \frac{t}{t_0} - \zeta\right) \tag{2}$$

where,

$\theta_s(t)$ – soil temperature at the contact with pipe wall unaffected by pipe [^{0}C];

ζ – thermal depth [m] (calculated according to depth and thermal properties of the soil) [10]**Error! Reference source not found.**:

$$\zeta = S_0 \sqrt{\frac{\pi \rho c}{t_0 \lambda}} \tag{3}$$

where,

S_0 – depth, [m];

λ – thermal conductivity of soil, [W/mK];

δc – volumetric heat capacity of soil, [J/m^{3}K].

The soil temperature at the contact with the pipe wall is influenced both by the heat transfer between the pipe and the inside air, the two influences are included in the U* coefficient being thus defined: [10]:

$$U^* = 2\pi \frac{\lambda}{U_{a,p}} \frac{1}{\ln\left(\frac{S_0}{R_0} + \sqrt{\left(\frac{S_0}{R_0}\right)^2 - 1}\right)} \tag{4}$$

where,

$U_{a,p}$ – heat transfer coefficient between air and wall of pipe, [W/mK];

R_0 – radius of pipe, [m].

Knowing the air temperature inside the pipe (θ_a), the correct soil temperature at the contact with the wall of the pipe ($\theta_{s,p}$) will be calculated with the formula [10]:

$$\theta_{s,p} = \frac{U^* \cdot \theta_s + \theta_a}{U^* + 1} \tag{5}$$

For finding the heat flow transferred from the earth to the air from the Canadian well one will divide the total length of the well into 100 segments (with the air temperature constant on a segment) and the heat exchange will be calculated for each segment [10]:

$$\dot{Q} = \Delta z \cdot U_{a,p}(\theta_{s,p} - \theta_a) \tag{6}$$

where,

$\dot{Q}$ – heat flow transferred from the earth to the air from the Canadian well, [W];

Δz - length of segment, [m].
The heat transfer coefficient between air and wall of pipe depends on the heat transfer coefficient at the inner surface of pipe [10]:

$$U_{a,p} = \pi(2R_0)h_i \tag{7}$$

where,

h_i – heat transfer coefficient between air and wall of pipe, [W/m^{2}K]; is calculated in function of air parameters of pipe material and its geometric characteristics [11]:

$$h_i = \frac{\lambda_a}{l_c} \cdot Nu \tag{8}$$

where,
Nu - Nusselt criterion;
l_c – characteristic length; in this case – diameter of pipe ($2R_0$), [m];
λ_a - thermal conductivity of air in pipe, [W/mK]; is determined from the table with air characteristics as function of air temperature.
The Nusselt criterion is calculated as function of Prandtl criteria (P_r – is determined from the table with air properties as function of air temperature and Reynolds (Re)) [11]:

$$\mathrm{Re} = \frac{w}{\nu_a} \cdot l_c \tag{9}$$

where,
ν_a - the kinematic viscosity of air, [m^2/s]; is calculated from the table of air characteristics as function of air temperature;
w - the speed of air in the pipe, [m/s] [12]:

$$w = \frac{D}{\pi \cdot R_0^2} \tag{10}$$

where,
D - the air flow that should be provided, [m^3/s];
For turbulent state, based on Gnielinski model, Nusslet is determined such as [10]:

$$Nu = 0.024(\mathrm{Re}^{0.8} - 100) \cdot \mathrm{Pr}^{0.4} \tag{11}$$

Knowing the air temperature at the well intake (equal to the external air temperature) on the basis of the heat flow written for each segment in turn, taking into account the limit conditions for the conservation of the heat flow, one could determine the air temperature variations along the Canadian well, as well as the heating/cooling potential of the passive house using the Canadian well system.

4. Implementing the model and simulation results

The model of Canadian well made for a passive house will be further analysed with GAEA application for the following input data:

- the geometric characteristics of Canadian well
    - number of piper: 1...5
    - pipe length: 20-60 m
    - pipe diameter: 100-300 mm
    - pipe depth: 1...3 m
    - distance with respect to house: 1m
    - distance between pipes: 1m
- soil characteristics
    - soil type: clay-sandy soil

  - soil thermal capacity: 2 MJ/m^3K
  - thermal conductivity: 2 W/mK
  - depth of ground water table: 6m
- climatic zone characteristics
  - Country: Romania
  - Town: Bucharest
- Heating/cooling system characteristics:
  - Air flow-rate: 165 m^3/h
  - Inside temperature 20°C
  - Heating limit 20°C
  - Cooling limit 26°C.

The Canadian well will operate as follows [13]:

- If the air temperature at the outlet of Canadian well is nearer the set temperature inside the rooms than then external air temperature, the well will start operating: otherwise, the input air temperature will coincide with the external air temperature(the well will not start operating);
- If the external air temperature is lower than the limit temperature imposed for heating then the well will start operating heating in the air taking over a heat flow from the earth;
- If the external air temperature is higher than the imposed limit temperature for cooling then the well will start operating cooling the air giving up a heat flow to the earth.

Starting from the input data presented above, for a pipe of 160 mm in diameter, 30 m long and 1.5 m deep, following the simulations made with GAEA application, one will firstly determine the air temperature at the exit from the Canadian well and also the values of the heat flow exchanged by the well with the earth.

In Fig. 3 there is represented the outlet air temperature variation with respect to the external air temperature variations, becoming evident that in comparison with the external air temperature presenting variations between -16.3°C and 35.9°C, the outlet air temperature from the well will show smaller variations, reporting a minimum of -1.6°C and a maximum of 23.5°C.

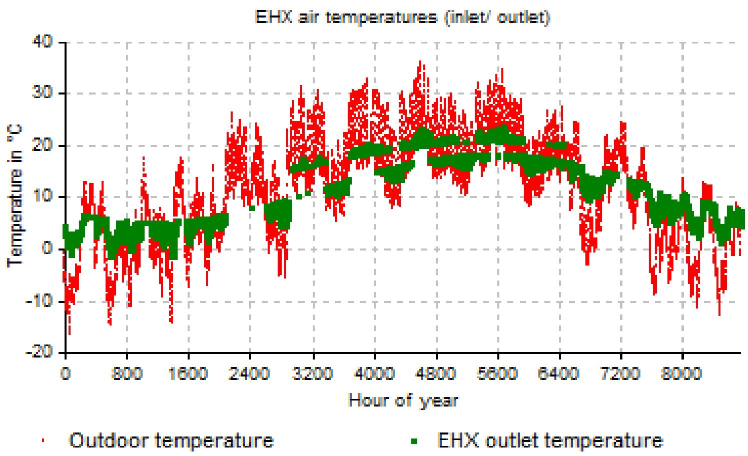


Figure 3. The annual variation of external air temperature and the annual variation of air temperature at the exit from the Canadian well [13]

The representation of heat flow variation exchanged by the Canadian well with the soil all along a year, sets into evidence the periods in which the Canadian well gets heat from the earth and periods when it gives up heat to the soil (Fig. 4).

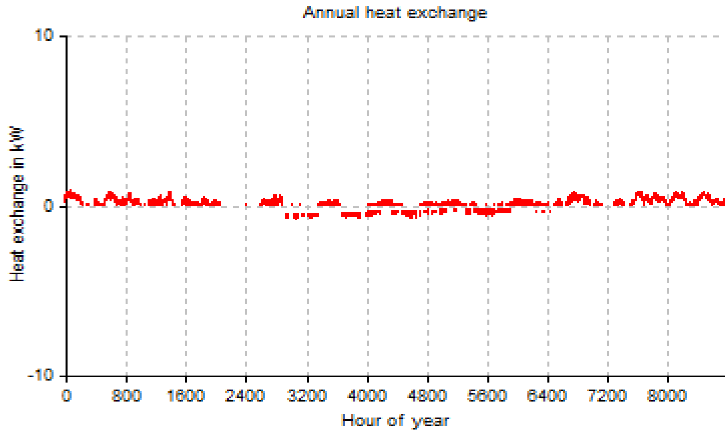


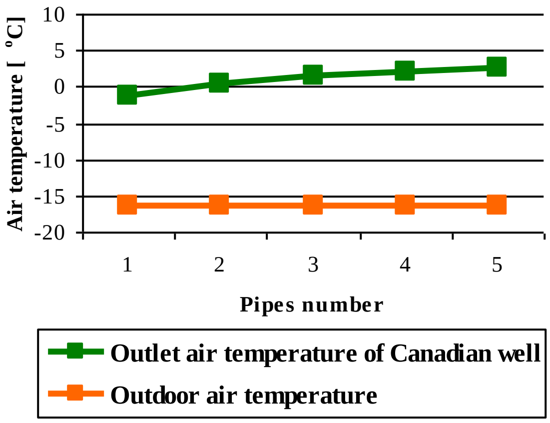
Figure 4. The annual variation of heat flow exchanged by the Canadian well with the soil [13]

In conformity with the simulations effected with the GAEA application the use of the Canadian well system presented, renders gains of heat of up to 1209.9 KWh in the cold seasons and thus diminishing the energy consumption at cooling of 267.4 KWh in the warm periods, contributing this way, to the reduction of energetic consumption of passive house for heating and cooling.
Starting from the model presented and keeping the same climatic data, and same soil characteristics and heating/cooling system, more Canadian well models will be analysed, altering, in turn, the following parameters:

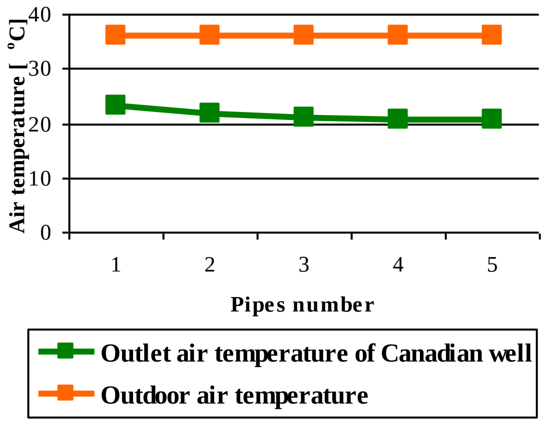
- Number of pipes
- Length of pipes
- Pipe diameter
- Mounting depth.

4.1 The influence of the number of pipes upon performance of Canadian well

Starting from the initial model made from a single pipe, more models of Canadian wells were considered for 2,3,4,5 pipes, keeping the other parameters constant. Following the simulation made, one observes that with the increase of the number of pipes higher temperatures are obtained at the exit from the Canadian well in winter, and lower temperatures in summer (Fig.5).



January 3 (at 24)



July 12 (at 17)

Figure 5. The influence of the number of pipes on the air temperature at the exit from the Canadian well for a cold winter day and a hot summer day.

Alongside with the increase of number of pipes the heating and cooling potential of Canadian well is also increased. So, in order to increase the energetic potential of Canadian wells one recommends the increase of number of pipes so that a speed of air circulation to be maintained within the recommended limits (1-3 m/s) (Fig. 6).

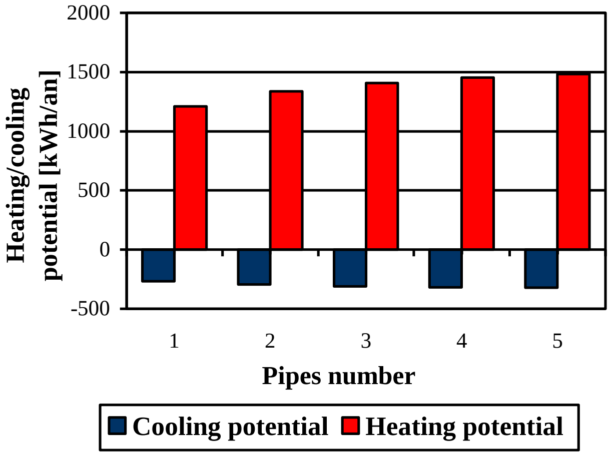


Figure 6. The influence of number of pipes upon heating/ cooling potential

4.2 The influence of pipe length upon performance of Canadian well

Starting from the model, more models of Canadian wells have been investigated, having lengths of 20,25,30,35,40,45,55,60 m, keeping all other parameters constant. With the increase of the pipe length the heating/cooling potential of the Canadian well also increases and at the same time, the energy losses also increase (Fig.7). So, for increasing the energetic performances of the Canadian wells longer pipes are recommended, though these are limited by minimizing the losses, which would result in an increase of electric energy by the fan and consequently in a decrease of the performances of the Canadian well system.

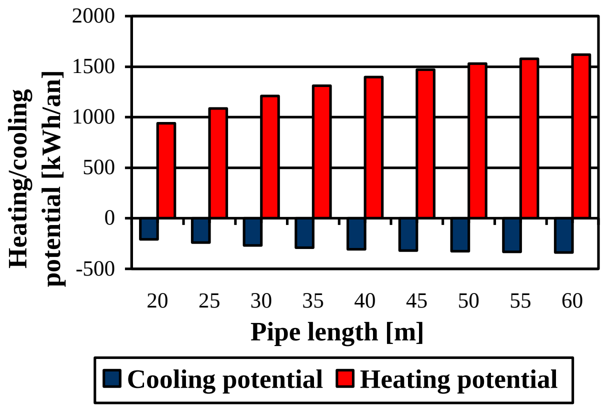


Figure 7. The influence of pipe length upon heating/ cooling potential

4.3 The influence of pipe diameter upon performance of Canadian well

Starting from the initial model, more versions of Canadian wells have been investigated with diameters of 100,150,200,240,300 mm keeping all other parameters constant. With the increase of diameter the flowing speed of air decreases, the convective heat exchange also decreases, thus reducing the heating/cooling potential of the Canadian well (Fig.8). So, for an increase of the Canadian wells performances, smaller diameters are recommended on the condition that the circulation speed of the air is maintained within regular limits.

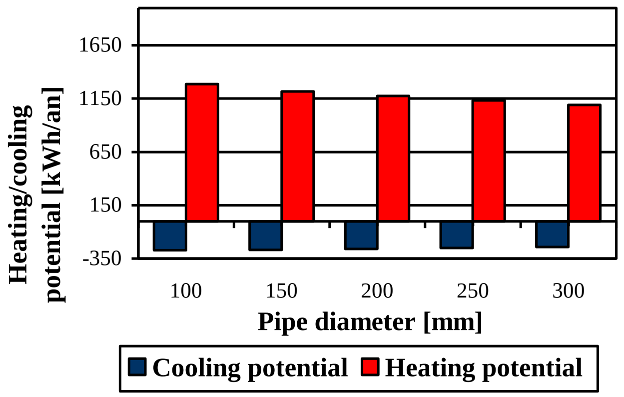


Figure 8. The influence of pipe diameter upon the heating/ cooling potential

4.4 The influence of pipe depth upon performance of Canadian well

Starting from the initial model, more versions of Canadian wells have been studied, with depths of 1, 1.2, 1.5, 2, 2.5 and 3 m keeping all other parameters constant. With the increase of the depth, the soil temperature increases in cold seasons and decreases in the warm seasons (Fig. 9), intensifying the heat flow exchanged by the Canadian well with the soil, thus, increasing the heating/cooling potential of the system (Fig. 10).

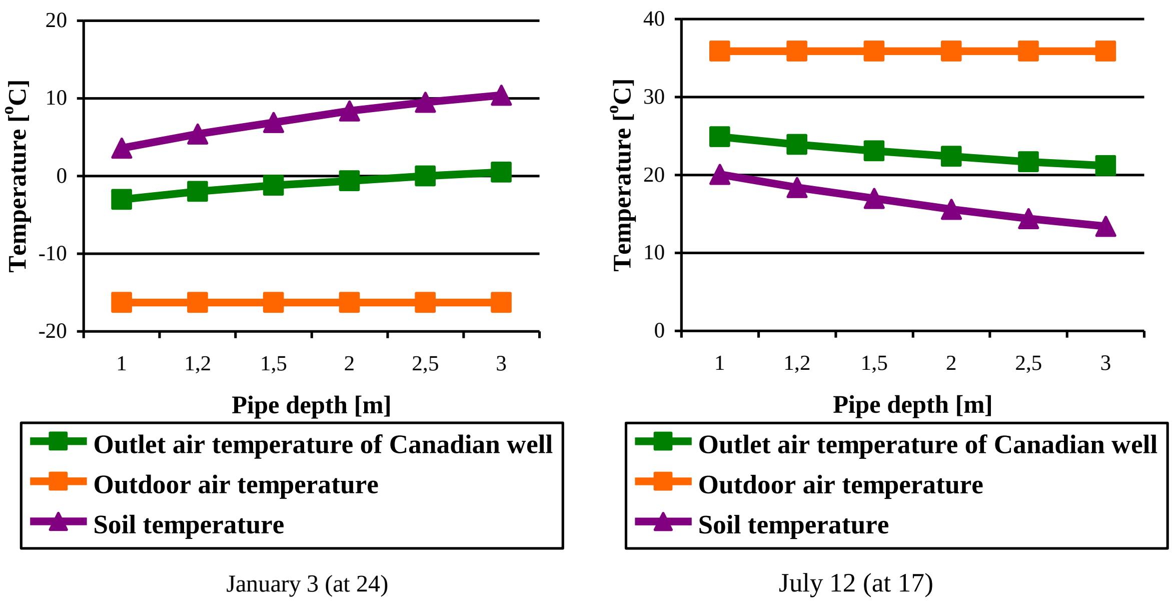


Figure 9. The influence of the mounting depth upon soil temperature and of exit air from the well during a cold winter day and a warm summer one

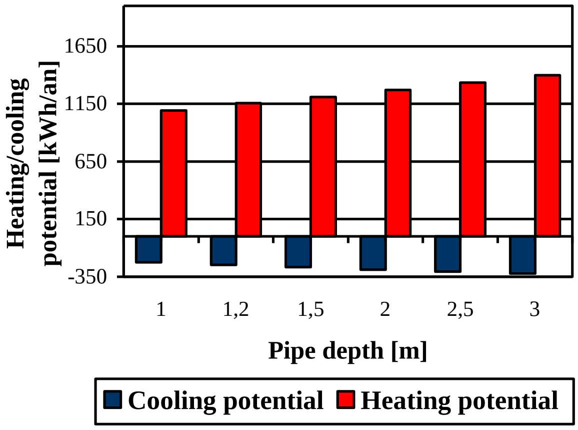


Figure 10. The influence of pipe depth upon the heating/cooling potential

So, energetically speaking, in order to increase the Canadian wells performances one recommends the mounting of pipe at greater depths, while from economical point of view, smaller depths are preferred, due to lower costs for digging volumes.
Analysing the various models achieved, for the same climatic conditions, same type of soils, the same fresh air volume, the optimum solution from energetic point of view, offering the highest energy gains, namely 2445 KWh yearly, will be represented by three Canadian wells made from pipes of 50 m length and a diameter of 150 mm, mounted at a depth of 3 m (Fig. 11).

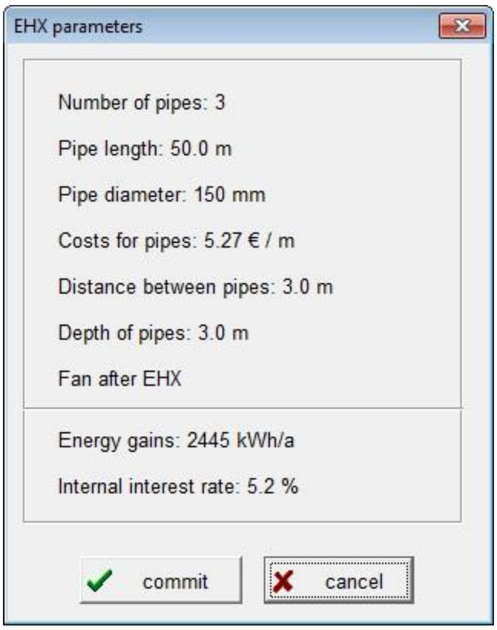


Figure 11. The optimum version from energetic point of view [13]

5. Conclusions

The increase of heating/cooling performances of passive houses will be achieved by preheating or cooling of external air as a result of heat exchange effected with the soil, through the agency of the Canadian wells.

Thus by their utilization, the input air temperature to the mechanically controlled ventilation system with heat recovery will not be the temperature of external air, but the exit temperature from the Canadian well.

This will result in significant savings of energy in the passive houses. For the selection of performant system of Canadian well, a decisive role is played by its parameters, namely: number of pipes, pipe diameter, pipe length, mounting depth.

In conformity with simulation made, the influence of Canadian wells parameters upon the increase of their performances by increasing their heating/cooling potential, meaning reduction of energetic costs, set into evidence the following:

- the performance of the Canadian well increases with the increase of number of pipes, with the mention that the air circulation speed recommended to be provided;
- the performance of the Canadian well increases with the increase of pipe length;
- the performance of the Canadian well decreases with the increase of pipe diameter, so, a larger number of pipes with small diameters are preferable;
- the performance of Canadian wells increases with the increase of mounting depth.

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