

Using heat pipes in greenhouse heating
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Abstrad

In the present work an instrumented heat pipe is designed, constructed and inserted inside a greenhouse to be used as a heating source during night or cloudy days in the cold months. Transferring geothermal heat from underground to the surrounding inside the greenhouse without consumption of conventional energy is one of the latest applications of the heat pipe device to transfer heat. The heat pipe is made of a sealed metal tube containing water as a working fluid. It is divided into three sections; the evaporator, adiabatic section and condenser. The buried part of the heat pipe is the evaporator section which transfers heat from the underground soil to the working fluid, which in turn, transfers heat to the condenser where it is rejected to the surrounding inside the greenhouse. This study was conducted on a greenhouse with an area of $(3.75)m^2$. Two heat pipes inserted at different depths inside the greenhouse soil were used to investigate the performance of this device. Results show an increase, with stability, of the environment temperature inside the greenhouse when the heat pipe is implemented in the cold and cloudy days of the cold winter months. The temperature inside the greenhouse reached $(20)^{\circ}C$ when the heat pipe inserted inside the soil to a level of $(3.5)m$ with heat transfer rate of $(126)W$, while the outside temperature was about $(14)^{\circ}C$.

Keywords : heat pipe ; greenhouse ; heating.

Introduction

Greenhouses mostly used in fall and winter months when temperature level of environment is low. In case of temperature decreases (below $14^{\circ}C$) it may cause damage to the plants(1990، بشير). To increase the temperature indoor, in that types of greenhouse plants heat pipe of course we'll be used to increase the inside temperature. In cold months it's possible to grow the plants in greenhouses without consuming additional energy by usage of underground heat pipe. Heat pipes are highly efficient heat transfer devices, which use the continuous evaporation and condensation of a suitable working fluid. Since the latent heat of vaporization is very large, heat pipes transport heat at small temperature difference with high rates.

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Due to a variety of advantage features, these devices have been used in a number of applications, both in space and terrestrial technologies. Some applications of heat pipes are in cooling electronic devices and heat recovery from exhaust ventilation (Shunji and Suzuki;(2000)).

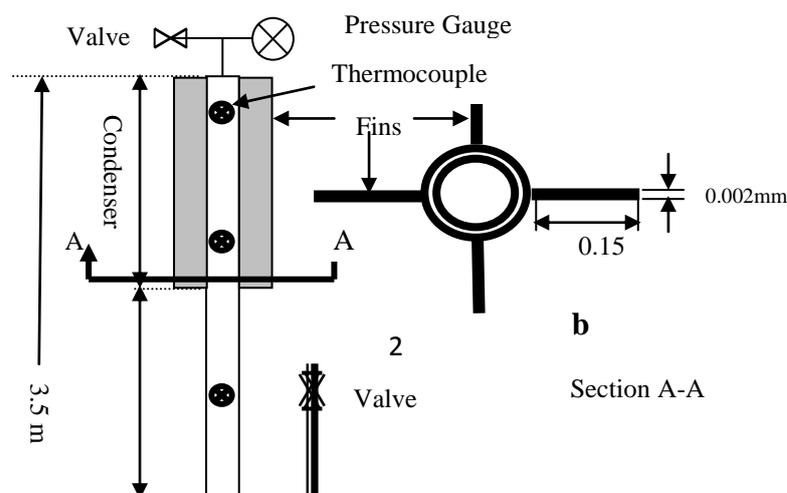
Experimental investigation of an instrumented heat pipe for domestic heating that uses water as a working fluid was carried out by (AL-Saadi, 2005). An experimental study concerned the development of an indirect type of solar cooker using a heat pipe inducted by (Yahya, 1980). Geological applications (Torrance, 2006). Heat pipe appliance can be seen in science industry and daily life as cooler or heat transport device between two environments with different temperatures. Theoretically heat pipe is able to transfer energy with temperature difference of 10°C . Useful output of this device is about 98%-99% (Reay, 2006). In this work heat pipes are used to heat the greenhouse by using underground as a heat source. It's inserted into the soil at the definite levels. This is the main advantage for the use of heat pipes to keep greenhouse temperature stable and higher.

1. Experimental Apparatus:

The rig used for this purpose has been designed and built in a greenhouse at college of agricultural and forestry field.

1.1: Structure and Principle of "Heat pipe"

As shown schematically in (Figure A), The heat pipe consists of a galvanized pipe of a diameter ($d_i=56\text{mm}, d_o=60\text{mm}$) and (2.5 to 3.5m) lengths of evaporator and longitudinally finned condenser that rejects heat to the environment through natural convection. The length of the condenser is (1.0m). Between the evaporator and condenser, there is an adiabatic zone. The variable operating conditions include different fluid charges with water as a working fluid and placed into the soil at different levels. Wick (one-layer stainless steel 100mesh screen) was inserted along the inside surface of the heat pipe. The fins were welded to the outside surface of the condenser as shown figure(1). Galvanized steel was chosen because of its resistance to corrosion with water. This explanation makes heat pipes sound very simple. The heat pipe was cleaned, sealed and evacuated to be prepared for usage.



1.2: Temperature Measurements

Seven calibrated thermocouples were used in temperature measurement, five on the outer surface of the HP; two thermocouples distributed along each evaporator, condenser and one in the adiabatic section. The temperature in the surrounding inside the greenhouse was read directly from a digital display.

1.3: Greenhouse characteristics

In this work the greenhouse used is composed of metallic frame covered by a double plastic shell. It's destined for growing different kinds of plants. As it's seen on figure(2). The greenhouse dimension are: length=2.5m; width=1.5m and height=2.5m, covering an area of 37m^2 .

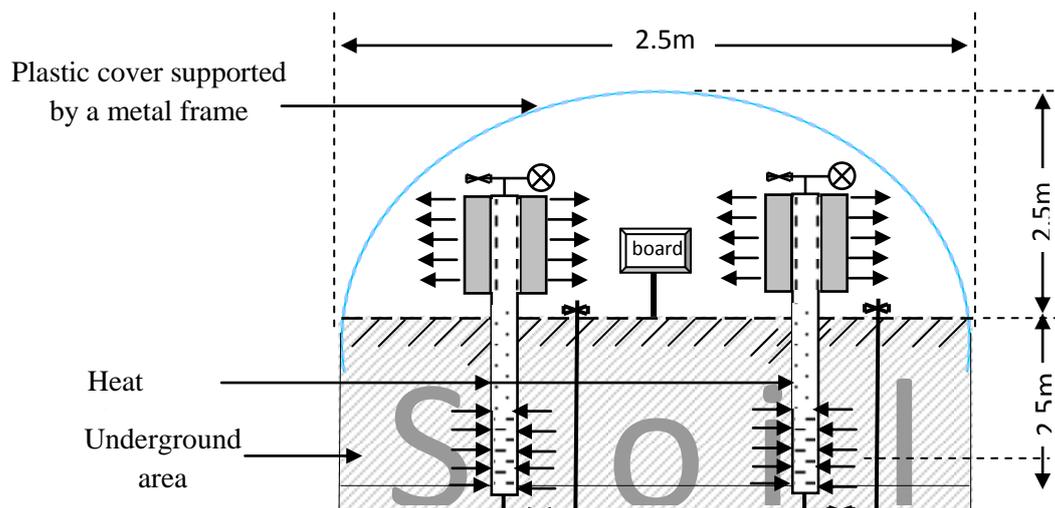


Figure (2): Greenhouse with an appliance of

2. Theoretical Model of Greenhouse Heating

A theoretical steady state model describing the performance of the heat pipe (HP) under a variety of operating conditions is developed below:

The energy balance of the heat pipe at steady state may be written as:

$$\text{Total power input to the evaporator} = \text{Heat rejected by the condenser}$$

2.1: Area enhancement due to fins

Inner diameter of pipe (d_i) = 0.056m.

Outer diameter of pipe (d_o) = 0.060m.

Length of fins and condenser (L_c) = 1.0m.

Width of fins (I) = 0.15m., Pitch (s) = 0.04m and thickness of fins (t_{fin}) = 0.002m.

The net surface area for two face = $A_{net} = 2 \times \text{fine surface} = 2 \times L_c \times I$

Where; N = the total number of fins = 4

A_{fin} : the total net surface area of fins = $N * A_{net}$

A_t : total surface area of condenser = $\pi \times d_o \times L_c$

The net surface area of unfinned pipe (A_{uf}) = $A_t - (\pi \times d_o \times s) \times N$

The total surface area of finned pipe = $A_f + A_{uf} = A_o$

Inside condenser area (A_i) = $\pi \times d_i \times L_c = 0.172m^2$

2.2: Fin Efficiency

The efficiency of finned condenser can be calculated by (El-Wakil , 1988)

$$\eta_{fin} = \frac{\text{Actual heat transfer}}{\text{heat transfer without fins}} = \frac{\tanh(mL)}{(mL)} \quad (1)$$

Where;

$$mL = I^{3/2} \times \sqrt{\frac{2h_c^*}{k_{fin} \times I \times t_{fin}}} \quad (2)$$

t_{fin} : Thickness of fins = 0.002m.

k_{fin} : Thermal conductivity

h_c^* : The combined heat transfer coefficient with the environment as defined latter by equation (7). The the surface efficiency (η_s) can be calculated as follows:

$$\eta_s = \frac{A_c}{A_{oc}} = \frac{A_{uf} + \eta_{fin} \times A_{fin}}{A_{uf} + A_{fin}} = 1 - \frac{A_{fin}}{A_{oc}} \times (1 - \eta_{fin}) \quad (3)$$

2.3: Heat Rejected by condenser

The heat rejected by the condenser to the surrounding inside the greenhouse, may be written as (Holman, 1990)

$$Q_c = A_c \times h_c \times (t_c - t_\infty) + A_c \times \sigma \times (t_c^4 - t_\infty^4) \quad (4)$$

Where;

Q_c = natural convection heat flow + radiation heat flow

h : heat transfer coefficient ($W/m^2 \cdot ^\circ C$)

T : temperature [$^\circ C$]

σ : Stefan-Boltzman constant = $5.669 \times 10^{-8} W/m^2 \cdot k^4$

c and ∞ : subscript refers to the condenser and ambient respectively .

The effective surface of the finned condenser (A_c) may be calculated by:

$$A_c = \pi \times d_o \times L_o \times E \times \eta_s \quad (5)$$

Where;

E : surface enhancement factor (Incorporeal, P.P1990.)

$$E = \frac{\text{Area of the condenser surface with fines}}{\text{Area of the condenser surface without fines}}$$

Equation (4), can be put into a more convenient form for numerical amputation by defining (h_c) for combined convection /radiation, Thus:

$$Q_c = A_c (t_c - t_\infty) + (h_c \times \sigma \times (t_c^3 + t_c^2 t_\infty + t_c t_\infty^2 + t_\infty^3)) \quad (6)$$

Thus the combined heat transfer coefficient (h_c^*) is

$$h_c^* = h_c \times \sigma \times (t_c^3 + t_c^2 t_\infty + t_c t_\infty^2 + t_\infty^3) \quad (7)$$

Equation (6) becomes:

$$Q_c = A_c \times h_c^* \times (t_c - t_\infty) \quad (8)$$

2.4: Free convection heat transfer coefficient in condenser

The natural convection heat transfer coefficient (h_c) is calculated by the following equations (Kreith, at.al . 2000).

$$Nu = \frac{h_c \times L_c}{k} \quad (9)$$

$$Nu = 0.17 (Gr^* \times Pr)^{1/4} \quad (10)$$

$$\therefore h_c = 0.17 \times \left(\frac{k}{L_c} \right) \times (Gr^* \times Pr)^{1/4} \quad (11)$$

$$Gr^* = Gr \times Nu = \frac{g \times \beta \times q \times L_c^4}{k_a \nu_a^2} \quad (12)$$

Where;

$$Gr = \frac{g \times \beta \times (t_c - t_\infty) \times L_{ct}^3}{\nu_a^2} \quad (13)$$

k_a : Thermal conductivity of air (W/m. K)

μ_a : Dynamic viscosity for air (N.s/m²)

ν_a : Kinematics viscosity for air (m²/ sec.)

g : Gravitation acceleration=9.81 (m/s²)

β : Volume expansion coefficient (1/°K)

Pr : Prandtl number

Nu :Nusselt number

Gr : Grashof number

Gr*: Modified Grashof number.

2.5: Number of heat pipes

The number of heat pipes required to be used inside the greenhouse is calculated according to the given environmental conditions as follows:

$$Q_c = A_c \times h_c^* \times (t_c - t_\infty) = 126W$$

$$A_c = \pi \times d_o \times L_c \times E \times \eta = 0.452m$$

$$Q_{req.} = U \times A_p \times \Delta T = 225W$$

$$\text{Number of HP} = \frac{Q_{req.}}{Q_c} \approx 2 \quad (14)$$

Where:

$Q_{req.}$: Heat required of greenhouse.

t_c : The condenser temperature =20°C

t_∞ : The ambient temperature =14°C

U : Overall heat transfer coefficient for plastic =2.2 W/m².K (Peterson, 1994)

A_p : The total plastic covering area of Greenhouse =17m²

From equation (7); By using Engineering Equation Solver Program (EES);

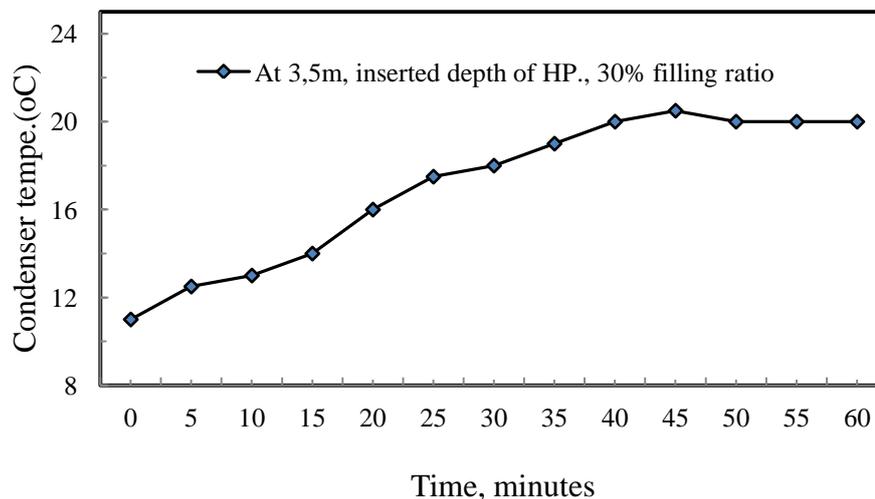
h_c^* : The combined heat transfer coefficient is found to be 70 W/m².K.

3. Experimental results and discussion

The experimental results that relate the basic parameters of the HP (average temperatures of the condenser and the evaporator surface) under various operating conditions (water inventory and different lengths of the evaporator were set into the soil) are presented and discussed along with performance indices represented by the heat transfer rate of the heat pipe and its efficiency. The results show that the temperature inside the greenhouse remains within the acceptable required temperature for plant growth. The results and relevant discussion are given as follow:

3.1: Transient behavior and steady state in the condenser HP

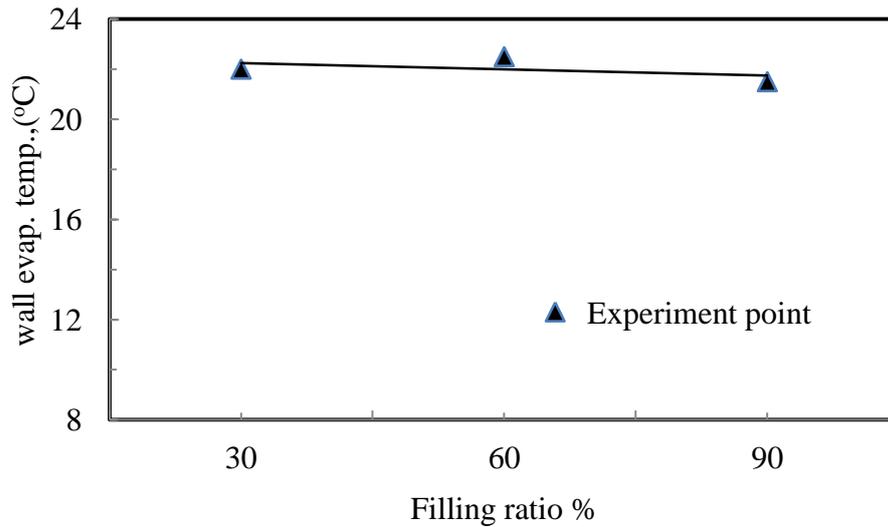
Figure (3) shows the transient behavior of a typical run for the heat pipe condenser. The familiar rise to the eventual steady state temperatures is shown. The behavior of the H.P was investigated experimentally and the rise time is around (40-50) minutes, to reach the steady state conditions.



Figure(3): Typical transient behavior of condenser.

3.2: Behavior of Heat Pipe with Water Inventory

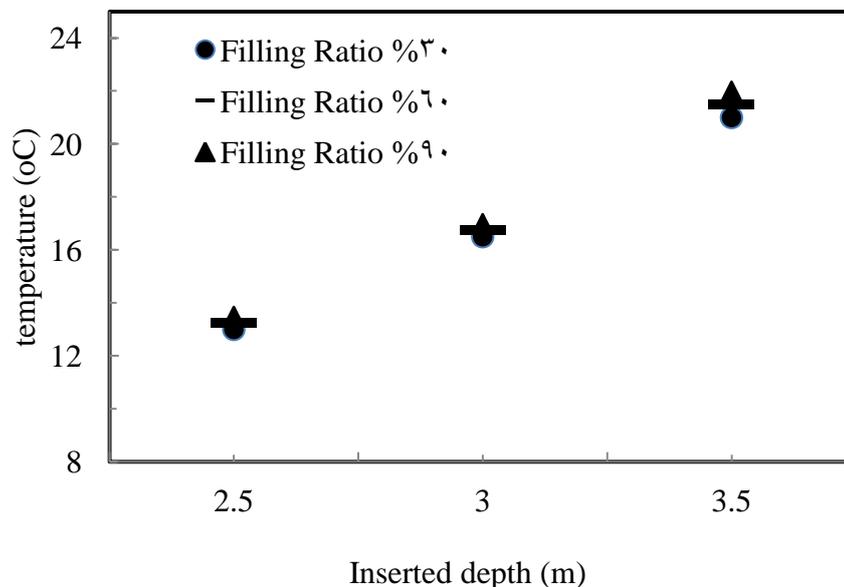
Figure (4) shows the average temperature of the evaporator in relation with the different filling ratios for HP length (3.5m). It is noted that the evaporator temperature is approximately constant.



Figure(4): Average temperature with different ratios

3.3: Distribution of Temperature along the outside wall of the HP

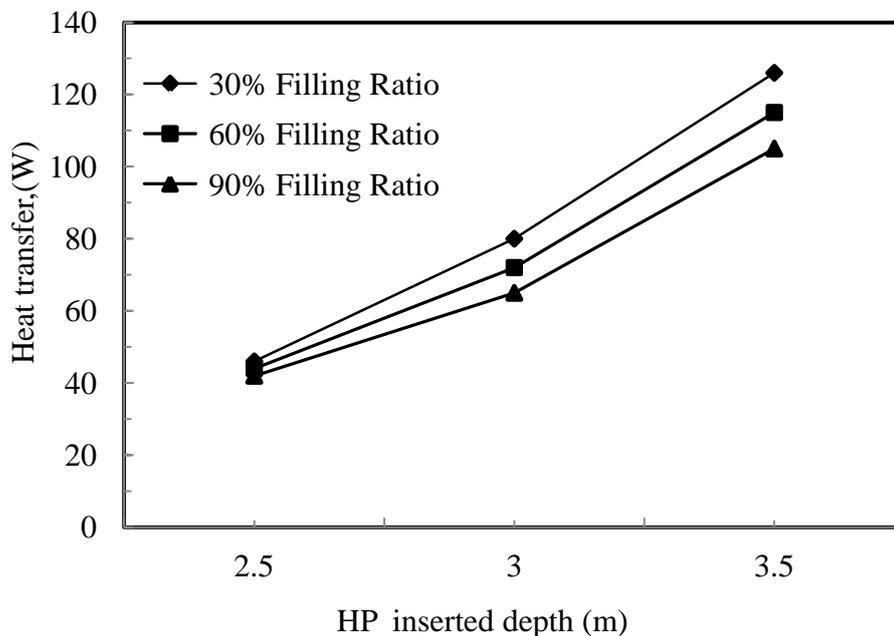
Figure (5) shows the relation between the temperature of the wall surface of the inserted section and the different inserted length of the evaporator inside the soil. Its clear from the figure that the inserted depth of the heat pipe in the soil should be more than (2.5) m to make the heat pipe working properly with acceptable efficiency.



Figure(5): Temperature of the wall surface of the inserted section vs. for different depth of HP with different ratios

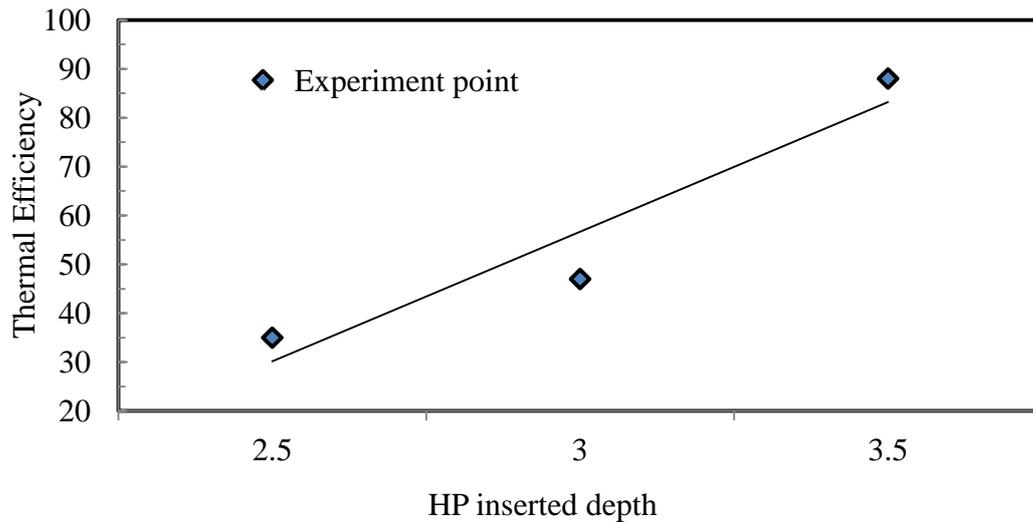
3.4: Maximum heat transfer rate

The heat transfer rate was implicit to be equal to the average of the heat transferred to the evaporator and the heat rejected by condenser under steady-state conditions. As shown in figure (6) the maximum heat transfer rate takes place at 30% filling ratio for all inserted depths of the evaporator. While it was found that at 2.5m depth HP is not efficient due to heat transferring by conduction only as the temperature in the ground at this depth doesn't accomplish to the boiling temperature of water corresponding to the vacuum pressure inside the HP. Also the heat transfer rate increases with the increase of evaporator depth inside the soil. The maximum heat transfer rate was 126W when the evaporator was buried to depth of 3.5m inside the soil and the filling ratio is 30%.



Figure(6): Heat transfer rat vs. the inserted depth. for different filling ratios

Figure (7) shows the thermal efficiency of transferring heat through the HP as a function of different levels of depth of the evaporator underground. The efficiency increases with the increased level of depth of the evaporator in the underground soil. It is clear from the figure that the efficiency is low at 2 and 2.5meter depth, and it is maximum when the depth is 3.5m and the filling ratio is 30%.



Figure(7): Efficiency of HP with the different inserted depth

Conclusions

From the present work, the following conclusions can be obtained:

- 1- Using heat pipes in greenhouses as a device to exploited effectively geothermal energy in heating during night or cloudy days in the cold months.
- 2- The maximum efficiency of the heat pipe obtained when it is burried to depth of (3.5)m and the filling ratio is (30%) to achieve surrounding temperature inside the greenhouse (20)^oC which is convenient to plant growth.
- 3- The heat pipe efficiency increases with the increase of the depth to which the heat pipe buried inside the soil.
- 4- The initial and running cost of such project is low compared with the conventional heating methods.
- 5- Design and construction of the system are simple with very low maintenance because there are no rotating parts. In addition, the heat pipe tube can be used as supporting frame for the greenhouse.

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استخدام أنابيب الحرارة في تدفئة البيت البلاستيكي
رفيق حمادي رجب
كلية الزراعة والغابات / جامعة الموصل/العراق

الخلاصة

في هذا البحث صمم وصنع أنبوب حراري لاستخدامه داخل البيوت البلاستيكية كمصدر للتدفئة ليلا والأيام الغائمة في الأشهر الباردة، بالاستفادة من الحرارة المخزونة في باطن الأرض بدون استهلاك للطاقة التقليدية، وذلك بتطبيق التقنية الحديثة في انتقال الحرارة بواسطة الأنبوب الحراري والذي هو عبارة عن أنبوب معدني مفرغ محكم يحتوي على الماء كمائع تشغيل. يتكون الأنبوب الحراري من ثلاثة اجزاء: المبخر، جزء ثابت الحرارة والمكثف. يدفن المبخر داخل التربة فتنتقل الحرارة من باطن الأرض إلى السائل الموجود في المبخر ثم تنقل إلى المكثف الذي بدوره يطرح الحرارة لمحيطه داخل البيت البلاستيكي. أجريت هذه الدراسة على بيت بلاستيكي بمساحة (3.75)م²، واستخدم اثنان من انابيب الحرارة ودفنا في التربة لمستويات عمق مختلفة تحت الأرض لمعرفة أداء الأنبوب الحراري. النتائج أظهرت زيادة واستقراراً في درجة الحرارة داخل البيت البلاستيكي في الأيام الباردة والغائمة من أشهر الشتاء الباردة وصلت إلى (20)م⁰، عند مستوى عمق (3.5) متر وبمعدل انتقال حرارة (126) واط بينما كانت درجة الحرارة خارج البيت البلاستيكي حوالي (14) م⁰