Thermal Performance and Payback Period Analysis of Solar Photovoltaic Cell (PV) Assisted Earth Air Tunnel Heat Exchanger (EATHE) in Summer for Bhopal, India

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Abstract— This investigation deals with analysis of solar photovoltaic cell (PV) assisted earth air tunnel heat exchanger (EATHE) for cooling in Bhopal, India. Today, the world faces the problems like ozone layer depletion, temperature hike, disturbance in human comfort etc. Due to the climate change caused by the refrigerants (CFCs) used in conventional air conditioning systems. When the room air is passing through the Earth tubes, the air is cooled in summer. Using this free energy, we can reduce the energy consumption required for space conditioning. For cooling of buildings, the EATHEs are considered as an efficient means. For renewable energy sources, many people are turning to the sun as a way to generate electricity without pollution. While solar energy definitely has rewards over traditional electricity generation, there are some drawbacks as well. It determines the possible production of green electricity from photovoltaic systems that could be used for air conditioning. The solar energy application through solar panel integrated EATHE for cooling is examined and compared to experimental values. The experimental setup was under operational conditions successfully during the year 2014-15. EATHE is a horizontal type closed loop system consists of mild steel pipe of 24 m long, 0.1584 m diameter and 3 mm thickness and it is buried below the ground surface at the depth of 3.048 m. The experimental set-up was used to studies the performance evaluation analysis of a solar photovoltaic system assisted earth air tunnel heat exchanger that is used for greenhouse cooling for various performance measures. In addition to this, payback period for solar panel aided EATHE is calculated. The payback period is 2.7 years. Calculation has been carried out using a temperature of 40^0C.

Key words: EATHE, Greenhouse, Payback Period, Earth Tube, Solar Energy, Coefficient of Performance

I. INTRODUCTION

In tropical climates, air conditioning is widely employed not only for industrial production but also for the comfort of occupants [5]. Certainly, India has a hot climate, but using EATHE, cooling demand can be minimized. Another way to lower the heating and cooling demand is to utilize the internal heat gain, that is, the heat generated within the building. The surplus heat can be stored in the structure of the building during shorter periods, such as a day, if the structure introduces a layer of material with good heat storage capacity exposed to the interior of the building.

The sustainable development of humankind builds upon efficient energy exploitation and environmental protection. According to the International Energy Agency-Energy Conservation in Building and Community Systems, approximately one fourth of total energy consumption in India were spent on space heating, cooling, lighting, and appliance operation in nonindustrial buildings. These buildings account for the largest share of CO2 emissions compared to other CO2 sources. The Kyoto-protocol stimulates the world to reduce CO_2 production [9].

To diminish the threat of global warming and energy depletion, research into building energy efficiency over the last decade has been undertaken to improve building service systems and specific construction components in order to create technologies and solutions.

Heat conduction in the ground has traditionally been a domain of researchers from the northern European countries. Because of the cold climate, they are more attracted by the field of foundation design, soil freezing, ground heat storage, and air pre-heating in earth-to-air heat exchangers. Researchers of the southern European countries often examine cooling potential of earth-to-air heat exchangers. The valuable information is often found in books or papers dealing with ground heat storage or thermo-active components (e.g. floor heating, radiant cooling ceilings).

One of the first investigations of heat extraction from the ground was launched by Johan Claesson [10]. Mathematically focused publication employed investigation of conduction equation with different boundary conditions. The analysis was based on the technique of superposition, when the complex thermal process in the ground was studied to be superposition of the elementary ones.

II. OBJECTIVES AND FORMULATION

One needs the proper tools to accurately simulate their performance and then to be able to achieve optimal design and control solutions. The present research proposes to meet the following objectives defined on the basis of research gaps identified by the author during literature review. The methodology employ to achieve the set objective is described in the next chapter. The objectives of this research are

- To review the state-of-the art of EATHE.
- A thermal model has been developed to investigate the potential of using the stored thermal energy of the ground for office building heating and cooling with the help of an EATHE system integrated with the solar system located in the TRUBA College, Bhopal, India.
- To determine the operating characteristics of EATHE in cooling and heating mode.
- To develop a database of its performance in each of the twelve months. To develop a thermal model to simulate the energy performance of EATHE.
- To study the airflow and heat transfer processes in large cross-sectional area EATHE and
- To develop a method to predict convective heat transfer in EATHEs.

The objectives of the present research will be achieved by addressing to the research questions.

In conventional ACs the electricity consumption is very high due to the temperature of area outside cooling system if temperature of surrounding is low than the power consumption will be low and if temperature outside cooling area is high than the power consumption will be high so the efficiency of the system will decrease due to varying power consumption [2]. The maintenance and running cost of this type of cooling system is high which results in high electricity bills so working can obsolete. Multiply the length; breadth and height of the room

Today, one of the most tragic things the world is suffering from a global warming. The main cause is ozone layer depletion which in turn caused by chlorofluorocarbons, which are extensively used in our conventional Air Conditioning System. The consequences are skin cancer (more UV rays from sun can reach the earth).

Depletion of ozone layer in the stratosphere is due to the Chloro-fluoro-carbons (CFCs) and additional halogenated substances which are created through artificial machines. when such ozone depleting chemicals reach the stratosphere, they are break down by ultraviolet light to liberate chlorine atoms. The chlorine atoms act as a catalyst, and such can break down tens of thousands of ozone molecules before being detached from the stratosphere.

III. THERMAL PROPERTIES OF SOIL

The ground temperature profile is strongly influenced by the material parameters of the soil [8]. When the ground is used as a heat source/sink two things happen that may significantly affect the performance of the heat exchanger. Moisture migration occurs as the temperature gradient in the ground increases, and in colder climates, the ground freezes. Although these aspects of ground heat transfer are not investigated in this thesis it is important to understand their effects.

The main parameter influencing the thermal behavior of the soil is the thermal conductivity and heat capacity can be jointly expressed under the term of thermal diffusivity:

$$\alpha = \frac{ks}{\rho s Cs}$$

Where, k_s are the thermal conductivity, ρ_s the density and c_s the specific heat of the soil. Thermal diffusivity determines the thermal behavior of the soil.

The soil temperature profile as a function of depth Z and time t. T_m and A_s are annual mean value and amplitude of the ground surface temperature variation respectively. The governing equation for soil temperature is [1, 9]:

$$T_{z,t} = T_m - A_s \exp^{-Z\,[(\frac{\pi}{365\alpha_s})^{1/2}]} \cos\{\frac{2\pi}{365}[t - t_0 - \frac{Z}{2}(\frac{365}{\pi\alpha_s})^{1/2}]\} \quad \text{..............(3.1)}$$

IV. THERMAL ANALYSIS

Following assumptions are made in the analysis of the EATHE system

- The Analysis is based on steady state conditions.
- The overall heat transfer coefficient is constant.
- The specific heat and mass flow rate of fluid is constant.
- The earth heat capacity is infinite.
- The soil properties around the pipe are isotropic, homogeneous and its conductivity along vertical and horizontal directions has a constant value.
- There is no change of phase of fluid during heat transfer.
- The changes in potential and kinetic energies are negligible.
- Axial conduction along the pipe is negligible.
- The flow inside the pipe is thermally and hydro dynamically developed.
- The thermal resistances encountered in heat transfer of EATHE are
- The resistance due to heat conduction through the solid wall separating the fluids.

$$R_{cd} = \frac{1}{2\pi L k_{pipe}} \ln\frac{D_o}{D_i} \quad (4.1)$$

Convection resistance on the inner surface of the tube for heat flow from fluid to wall.

$$R_{cv} = \frac{1}{\pi L D_i h_{air}} \quad (4.2)$$

The convective heat transfer coefficient h_{air} is calculated as a function of the air thermal conductivity (k_{air}) and the inner pipe diameter (D_i), with the classical expression:

$$h_{air} = \frac{Nu\, k_{air}}{D_i} \quad (4.3)$$

where the Nusselt number of the air (Nu) is done by the Gnielinski expression, as a function of the Reynolds and Prandtl numbers:

$$Nu = \frac{(f/8)(Re-1000)Pr}{1+12.7(f/8)^{1/2}(Pr^{2/3}-1)} \quad (4.4)$$

for $3000 \leq Re \leq 5\times10^6$

Reynolds number and (darcy) friction factor by the Petukhoc, in the case of circular pipes, is given by the following expression.

$$Re = \frac{\rho V D}{\mu} \quad (4.5)$$

$$f = (0.790 \ln Re - 1.64)^{-2} \quad (4.6)$$

for $3000 \leq Re \leq 5\times10^6$

In the earth tube heat exchanger (ETHE) air is the only heat transporting fluid. If the contact between soil and tube wall is considered to be ideal and the conductivity of the soil is taken to be very high compared to the surface resistance, then wall temperature at the within of the tube can be assumed to be constant. The total heat transfer to the air when flowing along buried pipe can be expressed as [7, 4]:

$$Q = m_{air}\, c_{p,air}\, (T_{air,out} - T_{air,in}) \quad (4.7)$$

Total heat transfer rate in the EATHE is given by the following equation:

$$Q = UA\Theta_m \quad (4.8)$$

The logarithmic average temperature difference is given by ($T_{soil} = T_{wall}$):

$$\Theta_m = \frac{(T_{air,in}-T_{wall})-(T_{air,out}-T_{wall})}{\ln[(T_{air,in}-T_{wall})/(T_{air,out}-T_{wall})]} \quad (4.9)$$

A. Coefficient of Performance (COP)

Coefficient of performance (COP) is used to give the efficiency indicator of ETHE [5, 1]. COP is determined as a ratio of total thermal energy gain from the ETHE and the mechanical dissipation energy [8]. Coefficient of performance is one of the measures of heat exchanger efficiency. It is defined as (ASHRAE 1985).

$$COP = Q_{out}/W_{in} \quad (4.10)$$

$$Q_{out} = m_a C_p (T_{air,out} - T_{air,in}) \quad (4.11)$$

B. The Overall Heat Transfer Coefficient

It is desirable and convenient to combine the various thermal resistances that are encountered in the heat transfer from one fluid to another in a heat exchanger. A necessary, and often the most uncertain, part of any heat exchanger analysis is determination of the overall heat transfer coefficient. It is defined in terms of the total thermal resistance to heat transfer between two fluids. The coefficient was determined by accounting for conduction and convection resistances between fluids separated by composite plane and cylindrical walls, respectively. For a wall separating two fluid streams, the overall heat transfer coefficient [3, 6, and 7] can be calculated as

$$U_i=1/R_tA_i \quad (4.2)$$

$$R_t=R_{cv}+R_{cd} \quad (4.3)$$

V. EXPERIMENTAL SETUP

The EATHE constructed at the Truba Institute of Engineering & Information Technology, Bhopal, India is a horizontal closed-loop system. Figure 5.1 shows the Solar Photovoltaic Cell (PV) assisted Earth Air Tunnel Heat Exchanger.

Fig. 5.1: Solar Photovoltaic Cell (PV) assisted Earth Air Tunnel Heat Exchanger

It consists of mild steel pipe of 24 m long, 0.1584 m diameter and 3 mm thickness. There is one pipe of 8 inch diameter, four pipe of 6 inch diameter, one pipe of 3 inch diameter, one insulating pipe, seven bands and four flanges.

It is buried below the ground surface at the depth of 3.048 m and 2 m away from the greenhouse. The length and spacing of serpentine pipes were 6m and 1.5m, respectively with three numbers of turns. The turns which are created through a 90° short elbow at the end makes the outlet horizontal to the entry of air. The pipe was spread under the ground in a serpentine manner after that trench was back-filled with the original soil. The inlet and outlet of the EATHE rise 0.5 m above ground surfaces. Inlet is coupled to the delivery end of blower and outlet is to room. The opening of suction and delivery end inside the greenhouse was covered with metal wire mesh to prevent the entry of insect and foreign matters. Airtight cover was used to join the buried pipes with the blower. A positive displacement of air (twin lobe compressor) type blower of 0.5 hp capacity is used to force air for flowing inside the tubes.

It was desired to obtain air temperature in the EATHE at various locations from entrance to the outlet. There are nine temperature sensors located inside the pipe: 0 m, 3 m, 6 m, 9 m, 12 m, 15 m, 18 m, 21 m and 24 m away from inlet to outlet of pipe w.r.t. test section where sensor are placed are as T1, T2, T3, T4, T5, T6, T7, T8 and T9 respectively as shown in figure 5.2.

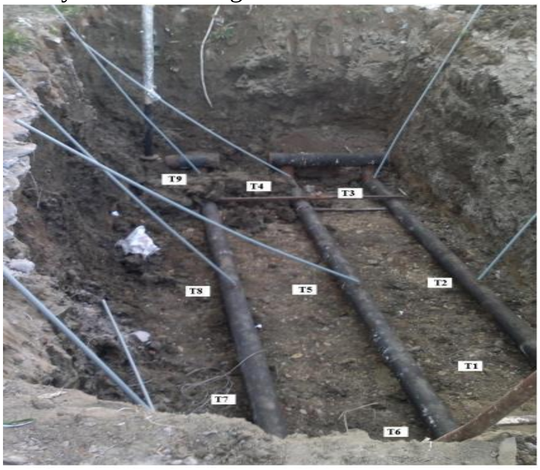

Fig. 5.1: Earth tube with sensors

Solar photovoltaic system is integrated with EATHE. Solar photovoltaic system consists of solar panel, charge controller, battery and DC motor of following specification.

PTC rating	224.3W
Maximum System Voltage (VDC)	600V
Nominal Max Power (P_{max})	250W
Optimum Operating Voltage (V_{mp})	30.6V
Optimum Operating Current (I_{mp})	8.17A
Open Circuit Voltage (V_{oc})	37.4V
Short Circuit Current (I_{sc})	8.95A

Table 5.1: Solar panel specification

Supported PV voltage	24V DC
Charging voltage cut	29 VOLT
Battery float voltage	27.6V
Charging Amp	20Amp
Battery Voltage	24 VOLT
Suggested Maximum PV	500W

Table 5.2: Charge controller specification

Model	RS455PA17150
Rated Voltage	DC 24V
Speed	4300 RPM
Current	0. 05A
Torque	16. 8 N-m
Shaft diameter	6 mm

Table 5.3: DC motor specification

A. Comparison of Theoretical and Experimental outlet air temperature in summer at velocity 1, 2, and 3 m/s and different inlet air temperature.

Time	**Outlet air temperature at different inlet temperature**					
	V = 1 m/s		**V = 2 m/s**		**V = 3 m/s**	
	Theoretical	**Experimental**	**Theoretical**	**Experimental**	**Theoretical**	**Experimental**
8.00 am	32.5	33.5	33.3	34.3	34.5	35.5
9.00 am	30.9	31.9	31.7	32.7	32.9	33.9
10.00 am	29.38	30.4	30.18	31.2	31.38	32.4
11.00 am	27.9	28.8	28.7	29.6	29.9	30.8

12.00 noon	26.5	27.4	27.3	28.2	28.5	29.4
1.00 pm	25.1	26	25.9	26.8	27.1	28
2.00 pm	23.85	24.65	24.65	25.45	25.85	26.65
3.00 pm	22.62	23.42	23.42	24.22	24.62	25.42
4.00 pm	21.45	22	22.25	23.05	23.45	24.25

Table 6.1: Outlet air temperature at velocity 1 m/s, 2m/s and 3 m/s in summer

B. Comparison of Experimental and Theoretical COP in summer at velocity 1, 2 and 3 m/s.

Time	COP					
	V = 1 m/s		V = 2 m/s		V = 3 m/s	
	Theoretical	Experimental	Theoretical	Experimental	Theoretical	Experimental
8.00 am	2.38	2.06	4.25	3.62	5.23	4.28
9.00 am	2.05	1.74	3.69	3.06	4.53	3.57
10.00 am	1.75	1.43	3.19	2.55	3.97	3.00
11.00 am	1.46	1.17	2.70	2.13	3.42	2.57
12.00 noon	1.18	0.89	2.23	1.66	2.91	2.05
1.00 pm	0.90	0.61	1.76	1.19	2.40	1.54
2.00 pm	0.65	0.39	1.35	0.84	1.93	1.17
3.00 pm	0.40	0.15	0.94	0.43	1.48	0.72
4.00 pm	0.17	0.09	0.55	0.17	1.05	0.29

Table 6.2: Experimental and Theoretical COP in summer at velocity 1, 2 and 3 m/s.

C. Comparison between theoretical and experimental outlet air temperature at 1m/s velocity of air in summer.

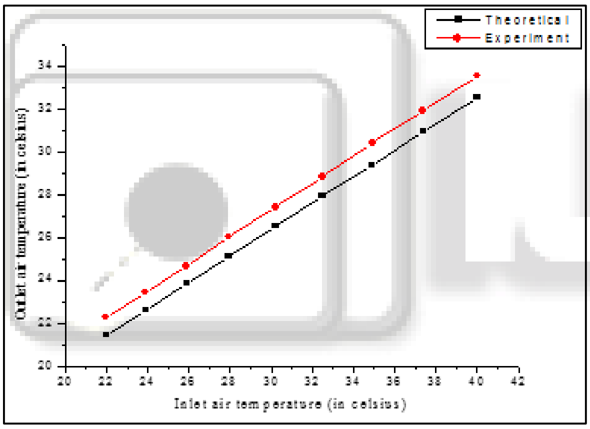

Fig. 6.1: Graph 6.1 Inlet air temperature vs outlet air temperature at 1 m/s.

D. Comparison between theoretical and experimental outlet air temperature at 2 m/s velocity of air in summer.

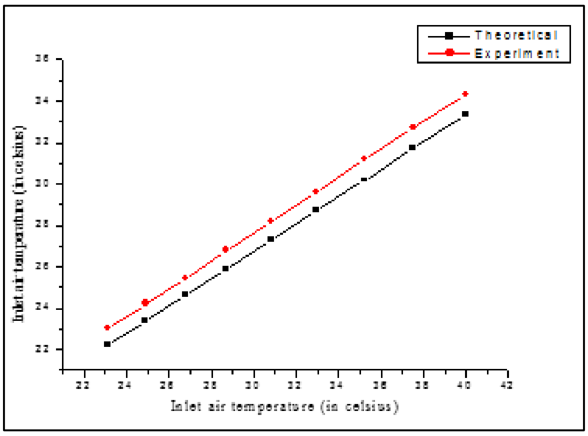

Fig. 6.2: Inlet air temperature vs outlet air temperature at 2 m/s.

E. Comparison between theoretical and experimental outlet air temperature at 3 m/s velocity of air in summer.

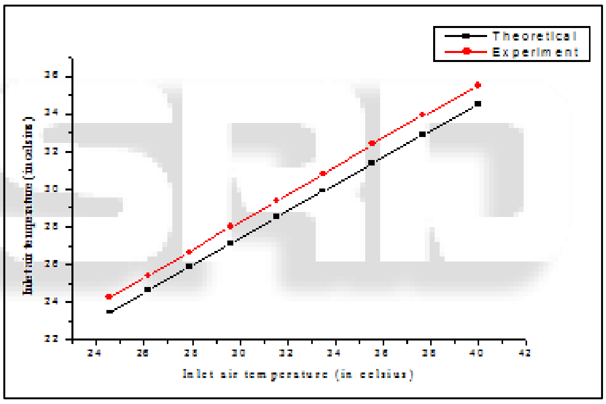

Fig. 6.3: Inlet air temperature vs outlet air temperature at 3 m/s.

It is clear from the Fig 6.1, 6.2 and 6.3 that outlet air temperature at velocity 1, 2 and 3 m/s and inlet air temperature 40 °C is 32.5 °C, 33.3 °C and 34.5 °C respectively. Theoretical and experimental outlet air temperature at velocity 1 m/s changes from 32.5–33.5 °C, 33.3−34.3 °C and 34.5−35.5 °C respectively for different inlet air temperature. Theoretical outlet air temperature variation at velocity 1, 2 and 3 m/s is 11 °C, 11.05 °C and 11.05 °C respectively.

F. Comparison of theoretical COP at velocity 1, 2 and 3 m/s of air in summer.

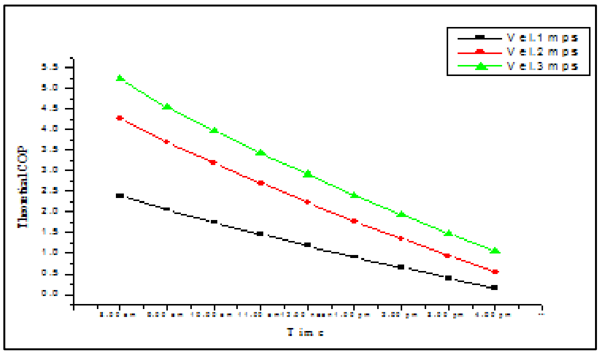

Fig. 6.4: Theoretical COP at velocity 1, 2 and 3 m/s.

It is clear from the graph 6.4 that theoretical COP at velocity 1, 2 and 3 m/s and inlet air temperature 40 °C is 2.38, 4.25 and 5.23 respectively. Theoretical COP at velocity 1 m/s, 2 m/s and 3 m/s changes from 2.38-.17, 4.25-.55 .32 and 5.23-1.05 respectively for different inlet air temperature.

G. Comparison of experimental COP at velocity 1, 2 and 3 m/s of air in summer.

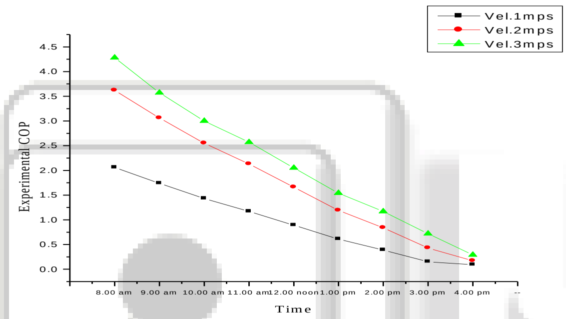

Fig. 6.5: Graph 6.5 Theoretical COP at velocity 1, 2 and 3 m/s.

It is clear from the graph 6.5 that theoretical COP at velocity 1, 2 and 3 m/s and inlet air temperature 40 °C is 2.06, 3.62 and 4.28 respectively. Theoretical COP at velocity 1 m/s, 2 m/s and 3 m/s changes from 2.06−.09, 3.62−.17 and 3.4.28−.29 respectively for different inlet air temperature**.**

VI. CONCLUSION

From the result it is concluded that

- The EATHE system drop the outlet air temperature in summer 7.5−18.55 □C. The variation in outlet air temperature at velocity 1 m/s, 2 m/s and 3m/s are 32.5−21.45 □C, 33.3−22.25 □C and 34.5−23.45 □C respectively.
- The EATHE with a low air velocity should result in reduction earth tube outlet air temperatures. Pipe length, pipe depth and air velocity inside pipe change to have more influence on thermal performance. However, pipe radius and air flow rate as well as cooling heat transfer rate also affect the performance of EATHE.
- The total average COP in summer is found to be range of 2.38 to 5.23. COP value was calculated for different air velocity like as 1 m/s, 2 m/s and 3 m/s respectively.
- The difference between experimentally and theoretically value of an outlet air temperature in summer are .55−.1 □C, .8−.1 □C and .8−1 □C for air velocity of 1 m/s, 2 m/s and 3 m/s respectively. The predicted and experimental temperatures of greenhouse air in the developed system showed fair agreement. It is concluded that there is possible for EATHE systems to make a useful involvement to energy saving in cooling.
- The Payback Period of Solar Panel in is 2.7 years.

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