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Comparative Study of Transient Conditions for Continuous Operation and Intermittent Operation of EATHE System Operated in Winter Season: A CFD Approach

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Abstract - The objective of the present work is to investigate the transient conditions of Earth Air Tunnel Heat Exchanger under intermittent operation using Computational Fluid Dynamics software FLUENT 6.3. Simulation runs have been carried out for winter heating case using three different soil thermal conductivities. Results obtained for intermittent operation of EATHE system have been compared with those obtained for continuous operation in terms of temperature rise of air and COP of the system. Simulations reveal that the rise in air temperature obtained during intermittent operation is better than that obtained during continuous operation of EATHE. These results shown significant improvement in heating potential during intermittent operation is observed for EATHE buried into soil having low thermal conductivity.

1. Introduction

To reduce peak load passive cooling system are recommended such as EATHE system. There are many reported experimental and analytical studies on EAHE. The ground temperature at depths of about 2 m to 3 m is practically independent of seasonal variation. During winter the ground temperature is higher than the ambient temperature and during summer it is lower. This offers great opportunities for coupling a building to the ground to provide favourable protection from adverse outdoor conditions, throughout the year. The indoor air is circulated through small diameter cylindrical ducts that are buried horizontally, at a depth of at least 2 m. Given the large thermal inertia of the ground, it can considered as a considerable heat source or heat sink, depending on the season.

As a space cooling technology utilizing natural energy, earth–air–pipe systems have attracted increasing interest for energy conservation [1–5]. Mihalakakou et al. [6–8] and Jacovides et al. [9,10] used earth–air–pipe heat exchangers in cooling agricultural greenhouses. Kumar et al. [11] evaluated the conservation potential of an earth–air–pipe system coupled with a building with no air conditioning. The cooling power for the earth pipe with length of 60 m, diameter of 0.10 m and air flow velocity of 5 m/s was 19 kW, which was adequate to maintain an average temperature of 27.65 °C for a single room in India. To improve the feasibility and comfort for space cooling, coupled a desiccant cooling set-up on the basis of the earth–air–pipe. A specific study on the thermal saturation and recovery of the soil under intermittent and continuous EAHX operation is performed by Mathur et al. [22].

2. Description of CFD model

Computational fluid dynamics (CFD) is used to solve the fluid flow, heat & mass transfer problems by dividing the objects into grid form and applying governing equations on each grid. CFD based model solved these governing equations in the form of partial differential equation. Numerical solution of these equation gives temperature and pressure distribution, flow parameters. CFD helps to reduce long tedious experimental work and enhance the accuracy of work.

To examine the air temperature rises in winter season of EATHE system, CFD software, FLUENT 6.3, was used. CFD software, GAMBIT 2.4.6 has been used to design and meshing 60 m long, 0.1 m diameter pipe. The model incorporates the effect of turbulent air flow on the thermal performance. The element type and the grid density were selected to be variable according to the sensitivity of temperature quantity, so that the calculation can adapt to the actual situation and reach a high level of accuracy. Because the temperature changes more sharply around the pipe wall, the grid is designed to be denser in that area, while it is sparser farther away from the pipe wall.

In the present study it has been assumed that air is incompressible and the soil is homogeneous and its physical properties are constant. It was also assumed that the property of the pipes and ground materials do not change with temperature and engineering materials used in the CFD model are isotropic and homogeneous.This was validated by experimental results.

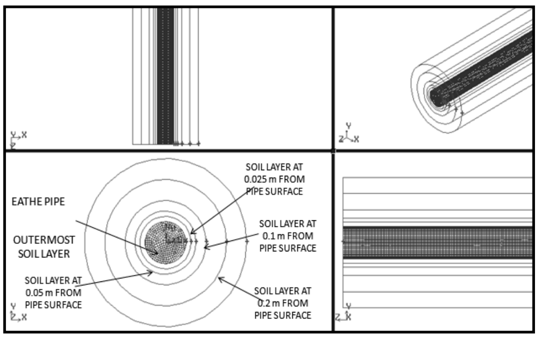

Figure 1. Four different views of CFD model for EATHE

Table 1. Boundary Conditions and geometric parameters used in simulation

Boundaries	Unit	Value
Air inlet temperature	K	280.6
Air Velocity	ms^{-1}	5
Soil temperature	K	300.2
Pipe Length	m	60
Pipe Diameter	m	0.1
Pipe inlet velocity	ms^{-1}	5

Thermo-physical parameters of materials used in simulation listed in table 2. These properties were fetched from depth of 3.7 m by physical testing other parameters were taken from Cucumo et. al.[12]. CFD model of 60 m length and 0.1 m diameter of pipe is validated with experimental result. The validated CFD model has been used for 24 h of intermittent operation. Ajmi et al.[13] reported that no significant effect of soil surrounding the pipe has been occurred therefore, for study purpose diameter of soil cylinder has been taken two times of pipe diameter.

3. Experimental set-up:

The mentioned diagram Figure 2 shown experimental set-up of EATHE, having 60 m long horizontal PVC pipe of inner diameter 0.10 m buried underground at depth of 3.7 m. for movement of air in EATHE pipe single phase blower is connected. The depth of 0 m, 0.62 m, 1.24 m, 1.86 m, 2.48 m, 3.10 m and 3.7 m respectively from ground surface.

Table 2. Thermo-Physical parameter used in simulation

Parameters	Density kgm^{-3}	Thermal conductivity $Wm^{-1}K^{-1}$	Specific heat capacity $Jkg^{-1}K^{-1}$
Air	1.225	0.0242	1006
Soil (SL1)	2050	0.52	1840
Soil (SL2)	2050	2.0	1840
Soil (SL3)	2050	4	1840
PVC	1380	1.16	900

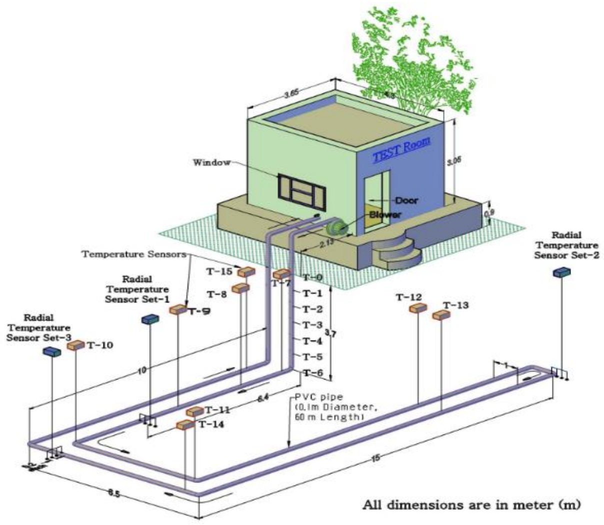

Figure 2. Schematic of room integrated EATHE system

Additional RTD has been installed along the pipe length, T_7, T_8, T_9, T_{10}, T_{11}, T_{12}, T_{13}, T_{14} and T_{15} at 0.2 m, 1.7 m, 4.7 m, 9.3 m, 15.1 m, 24.2 m, 34.0 m, 44.4 m and 60.0 m respectively from inlet point of pipe to measure air temperature. A group of four RTD (Pt-100) temperature sensors at axial distance of 6.4 m, 27.4 m and 48.8 m from the inlet of EATHE were also provided to measure the temperature of pipe–soil interface, temperature of soil at a distance of 0.2 m, 0.4 m and 0.6 m from pipe surface, respectively.

4. Validation of simulation model:

In this exercise, this grid independency test mainly used for checking the effects of mesh size on accuracy of solution. So, this graph revealed that inlet point of pipe maintains temperature 312.6 K, 312.6 K, 312.6 K by coarse, medium and fine mesh respectively. Similarly, at 30 m away from pipe surface these temperatures reduce till 302.7 K, 301.7K and 301.6K by coarse, medium and fine mesh respectively. Similarly, at outlet of pipe temperature reduce till 301.3 K, 300.3 K and 300.2 K by coarse, medium and fine mesh respectively.

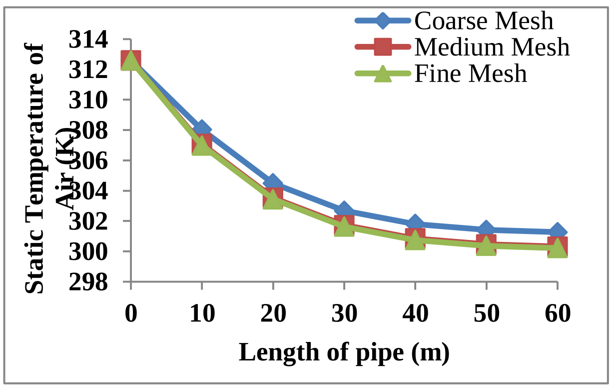

Figure 3. Validation of EATHE system

Study of transient behavior of EATHE system in continuous operation:

Soil layers surrounding the pipe have also been simulated to study the transient effects of thermal conductivity of soil on the thermal performance of EATHE system by using three different types of soil SL1, SL2 and SL3. Comparison of simulated and experimental values of temperature of air in the pipe at various points along the length is summarized for air velocity of 5 m/s.

5. Following modes of operation of EATHE system under transient conditions have been investigated

Thermal performance of EATHE system operating under various intermittent mode (Mode 2) has been compared with the continuous mode of operation (Mode 1) in terms of rise in air temperature along the length of pipe.

5.1. Continuous mode (Mode 1)

In this operation a long pvc pipe has been used. It has analyzed by using three types of soils, having different thermal conductivities which are mentioned in thermo-physical condition. Air temperature of winter season has been assumed about 280.6 K and surrounded soil possessed near 300.7 K. when air pass through the pipe due to temperature difference heat transfer occurs at pipe-soil interface. Pipe gets heated up by the soil. Two mode of heat transfer has been noticed in EATHE system, conduction mode occurs in between soil and pipe, convection mode occurs in between pipe and air. During running position heat will accumulating between soil layers which creates thermal influence zone and degrade thermal performance by time.

5.2. Intermittent mode (Mode 2)

In this mode EATHE system has been used intermittently. It is used continuously for 12 hours and then kept OFF for next 12 hours making ON-OFF cycle of 24 hours duration. For the use of EATHE in such a manner one cycle of intermittent operation shall be obtained.

Hourly variation in air temperature at outlet section of EATHE pipe buried in soil (SL) with lowest thermal conductivity (SL1= 0.52 $Wm^{-1}K^{-1}$), medium thermal conductivity (SL2= 2.0 $Wm^{-1}K^{-1}$) and highest thermal conductivity (SL3= 4.0 $Wm^{-1}K^{-1}$) during intermittent operation (Mode 2) have been compared with that obtained during continuous operation (Mode 1) in Fig 4-6.

Figure 4 shown that at outlet section of the length of pipe buried under soil (SL1) is obtained 297.8 K after 25th hour during continuous operation (Mode 1). However corresponding value obtained during intermittent mode of operation (Mode 2) is 299.4 K after 25th hour.

Figure 5 shown that at outlet section of the length of pipe buried under soil (SL2) is obtained 299.8 K after 25th hour during continuous operation (Mode 1). However corresponding value obtained during intermittent mode of operation (Mode 2) is 300.0 K after 25th hour.

Figure 6 shown that at outlet section of the length of pipe buried under soil (SL3) is obtained 300.1 K after 25th hour during continuous operation (Mode 1). However corresponding value obtained during intermittent mode of operation (Mode 2) is 300.1 K after 25th hour.

6. COP ANALYSIS

Coefficient of performance of EATHE system under continuous and intermittent modes of operation has been determined with the help of formula given as

$$\text{COP} = \frac{\dot{m} * C_p * \Delta T * C_d}{q_{in}} \qquad (1)$$

Where, $\dot{m} = \rho_a A V_i$

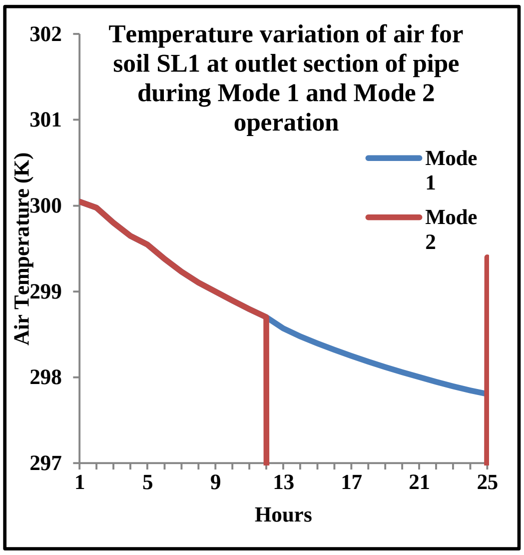

Figure 4. Hourly temperature of air for soil SL1 at outlet section of pipe (0.1 m diameter) at 5 m/s flow velocity for Mode 1 and Mode 2

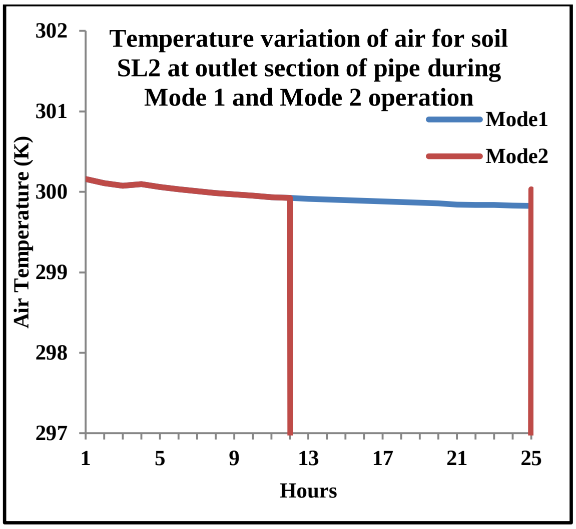

Figure 5. Hourly temperature of air for soil SL2 at outlet section of pipe (0.1 m diameter) at 5 m/s flow velocity for Mode 1 and Mode 2

$\dot{m}$ = mass flow rate of air (kg/s), V_i = Flow velocity of air (m/s), ρ_a = Density of air (kg/m^3), C_p = Specific heat of soil and q_{in} = Energy input to the blower (W).

Typical values of above parameters are $\dot{m}$ = 0.048 kg/s, C_p = 1005 Jkg^{-1}K^{-1}, $\Delta T = T_{out} - T_{in}$, C_d (Coefficient of discharge) = 0.6, q_{in} = 120 W, T_{out} = Hourly temperature at 60 m; T_{in} = Hourly temperature at inlet point.

It is observed from Table 3 that for continuous mode (Mode 1) the average COP is 4.4, 4.7 and 4.7 for SL1, SL2 and SL3 respectively. However, corresponding values of COP for intermittent mode (Mode 2) are 4.5, 4.7 and 4.7 for SL1, SL2 and SL3 respectively

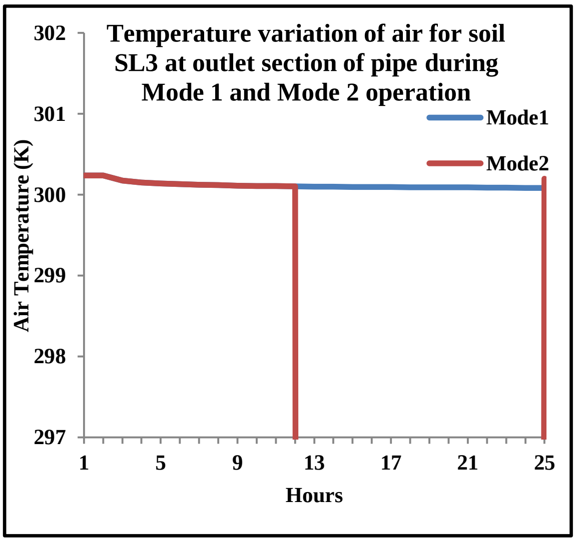

Figure 6. Temperature of air for soil SL3 along the length of pipe (0.1 m diameter) at 5 m/s flow velocity for Mode 1 and Mode 2

Table 3. Average COP

Mode	SL1 (0.52W/mK)	SL2 (2 W/mK)	SL3 (4 W/mK)
Mode-1	4.4	4.7	4.7
Mode-2	4.5	4.7	4.7

CONCLUSION

The main concluding remarks of the study are as follows:

1. Thermal performance of EATHE system in intermittent operation (Mode 2) increases the outlet air temperature of EATHE system by 8.13%, 1.04% and 0.01% for SL1, SL2 and SL3, respectively. These results show that during non-working time period of EATHE system soils are regenerated by dissipating the accumulated heat to subsequent soil layers which helps to improve thermal performance of EATHE system.

2. Coefficient of thermal performance of EATHE system in intermittent operation (Mode 2) is increase by 0.1 for lowest thermal conductivity soil (SL1) where as high thermal conductivity doesn't affect the coefficient of thermal performance of EATHE system.

3. Operating the EATHE in intermittent mode found to be very useful. Heat accumulation in the nearby soil during continuous operation of EATHE system can be minimized by running the system in intermittent mode. This study also revealed that EATHE system with higher thermal conductivity soil (SL3) can be operated continuously (Mode 1) while EATHE system with lower thermal conductivity (SL1) must be used in intermittently (Mode 2).

Table 4. Temperature rise of air at outlet section of pipe after 24 hours of continuous operation (Mode 1) and intermittent operation (Mode 2)

Soil	Mode 1	Mode 2	Improvement %
SL1	17.2	18.8	9.30
SL2	19.2	19.4	1.04
SL3	19.5	19.5	0.00

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