Energy and Buildings 87 (2015) 360–369

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Thermal performance investigation of earth air tunnel heat exchanger coupled with a solar air heating duct for northwestern India

Sanjeev Jakhar[a,*], Rohit Misra[b], Vikas Bansal[c], M.S. Soni[d]

[a] Center for Renewable Energy and Environment Development, BITS – Pilani, Rajasthan, India
[b] Mechanical Engineering Department, Government Engineering College, Ajmer, India
[c] Mechanical Engineering Department, University College of Engineering, Kota, India
[d] Department of Mechanical Engineering, BITS – Pilani, Rajasthan, India

ARTICLE INFO

Article history:
Received 26 September 2014
Received in revised form
24 November 2014
Accepted 26 November 2014
Available online 3 December 2014

Keywords:
Earth air tunnel heat exchanger
Solar air heating duct
Heating capacity
Thermal performance

ABSTRACT

In the present research thermal performance of earth air tunnel heat exchanger (EATHE) coupled with a solar air heating duct has been experimentally evaluated for arid climate of Ajmer city of northwestern India, during winter season. An attempt has been made to enhance the heating capacity of EATHE system by coupling it with a solar air heating duct at the exit end. Results show that the air which comes out of coupled EATHE system is relatively hotter than the air supplied by the stand alone EATHE system. It was found that the heating capacity of EATHE system got increased by 1217.625–1280.753 kWh when it was coupled with solar air heating duct with a substantial increase in room temperature by 1.1–3.5 °C. The COP of the system also increased up to 4.57 when assisted with solar air heating duct. Therefore, the heating capacity of EATHE can be significantly increased by coupling it with solar air heating duct.

1. Introduction

With the rapid growth in population and economic growth of countries in the tropical regions, it is becoming inevitable that passive and low energy strategies must be used as suitable alternatives for heating/cooling. The utilization of geothermal energy to reduce heating and cooling needs in buildings has received increasing attention during the last several years. The potential of earth–air heat exchanger has been established in moderate climates of Europe, however not much research has been carried out in hot climates because of the claim that the potential is low. The use of passive heating techniques in the winter is advisable, with the objective of reducing energy consumption with the climatisation of spaces. It can thus be an effective tool for attenuating the growth of energy consumption for air conditioning.

To ensure indoor air quality, building needs adequate ventilation. Many commercial and industrial buildings need to have high ventilation rates. During winter, fresh cold air needs to be warm up before supplying to the buildings, thus consuming more energy. Preheating of external air before entering the building can be achieved by natural means, like circulation in buried pipes [1,2]. To reduce high grade energy consumption of conventional active heating systems, numerous alternative techniques have been explored. One such proposition is the earth air tunnel heat exchanger (EATHE) system. EATHE works in principal on geothermal energy with temperature variation.

Soil temperature, at a depth of about 10 feet or more, stays fairly constant throughout the year and is approximately equal to the average annual ambient air temperature. The ground can, therefore, be used as a heat source for heating in winter. Cold outdoor air is sent into the earth air tunnel heat exchanger. When air flows in the earth air tunnel, heat is transferred from the earth to the air. As a result, the air temperature at the outlet of the earth air tunnel heat exchanger is much higher than that of the ambient. The outlet air from the earth air tunnel can be directly used for space heating if its temperature is high enough. Alternatively, the outlet air may be heated further by associating air conditioning machines and solar air heating duct. Both of the above uses of earth air tunnel heat exchanger can contribute to reduction in energy consumption. The main advantages of the system are its simplicity, high preheating potential, low operational and maintenance costs, saving of fossil fuels and related emissions. Pre-heated fresh air

Abbreviations: EATHE, earth air tunnel heat exchanger; PVC, poly vinyl chloride; RPM, revolution per minute; DBT, dry bulb temperature of air (°C); COP, coefficient of performance.

* Corresponding author. Tel.: +91 1596 516455.
E-mail addresses: sanjeev.jakhar@pilani.bits-pilani.ac.in, sanjeevj450@gmail.com (S. Jakhar).

http://dx.doi.org/10.1016/j.enbuild.2014.11.070
0378-7788/

supports a heat recovery system and can reduce the space heating demand in winter. The potential of earth tube air heat exchanger for space heating is well accepted in colder countries.

As reported by Bansal et al. [3] not much research has been carried out in hot climates (such as in western India) because of the belief that the cooling potential of EATHE system is low due to higher soil temperature in summer. Santamouris et al. [4] investigated the impact of different ground surface boundary conditions on the efficiency of earth-to-air heat exchanger consisting of single and multiple parallel pipes and concluded that ground surface covered with short grass gives better cooling performance than bared soil condition. Hwang et al. [5] studied the performance of an innovative evaporative condenser and compared it with that of a conventional air-cooled condenser of a split heat pump system. Their experimental results showed that the evaporative condenser has a higher capacity than the air-cooled condenser by 1.8–8.1%, a higher COP by 11.1–21.6%. Hajidavalloo [6] investigated the effect of using evaporative cooler in the window-air-conditioner by injecting water on the media pad installed in front of the condenser entrance and reported 16% reduction in power consumption and 55% improvement in total performance. Most of the research has been carried out through mathematical modeling or experimental investigations.

As a space cooling technology utilizing natural energy, earth–air–pipe systems have got increasing interest for energy conservation [7–9]. Kumar et al. [10] 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 was evaluated as 19 kW for pipe length of 80 m with section area of 0.53 m^2 and air flow velocity of 4.9 m/s. Ajmi et al. [11] studied the cooling capacity of earth–air heat exchangers for domestic buildings in a desert (hot and arid) climate. A reduction of 30% in seasonal cooling demand was reported by using the earth-to-air heat exchanger in July. Ramirez-Davila et al. [12] performed a numerical study on the thermal behavior of an earth to air heat exchanger (EATHE) for three cities in Mexico with varying climatic conditions. Results showed that use of EAHE was appropriate for extreme and moderate temperature regions where the thermal inertia effect in soil is higher. Santamouris et al. [13] developed a new integrated method to calculate the role of earth to air heat exchangers to reduce the cooling load of the buildings based on the principle of balance point temperature.

Badescu [14] developed a ground heat exchanger model based on numerical transient bi-dimensional approach for passive house space heating. Sodha et al. [15] evaluated an earth–air tunnel system for cooling/heating to provide thermal comfort inside the whole building complex at one of the hospitals in India. Their results showed that an 80 m long tunnel with a cross sectional area 0.528 m^2 had a 512 kWh cooling capacity and 269 kWh heating capacity. Exergo-economics analysis was carried out by Ozgener and Ozgener [16] to determine the optimal design of a closed loop earth to air heat exchanger for greenhouse heating. Hollmuller and Lachal [17] discussed the potential and climate independent design guidelines of buried pipe systems. The design guidelines were validated using a system described by the authors. Poshtiri et al. [18] performed the feasibility study of the combined system of EAHE with a solar chimney. Similar work has been done by Maerefat and Haghighi [19]. They designed EAHE system coupled with solar chimney for both cooling and ventilation. Numerical modeling was performed for the system to optimize the diameter of pipe, which gives the minimum required number of solar chimney and EAHEs. The literature review reveals that there exists a gap to correlate the potential of solar air heating duct coupled with EAHTE system.

According to Sodha et al. [15], the heating capacity of standalone EATHE is not adequate to provide necessary comfort conditions for Indian conditions. And hence to enhance the performance of EATHE systems, a solar air heating duct is coupled in the present study. An experimental investigation has been carried out for different modes, operating for 8 h daily incorporating the winters during January and February. An attempt has also been made to explore the validity and effectiveness of the employed EATHE coupled with a solar air heating duct system for heating in cold conditions. The heating capacity and coefficient of performance (COP) of the system were found to be in agreement for the enhancement of results.

2. Description of test facility and test unit of EATHE coupled with a solar air heating duct system

The test location of the system was in the city of Ajmer, located in northwestern India, which has hot semi-arid climate having the absolute maximum and mean maximum ambient air temperatures during summer period (April to June) as 47 °C and 39 °C respectively. The average ambient temperature during summer ranges from 30 to 32 °C. During winters (November to February), the weather remains mild and average ambient temperature ranges between 15 and 18 °C. During winter, the absolute minimum and mean minimum temperatures of ambient air are close to 4 °C and 9 °C respectively. The annual average ambient temperature of the location is 26.7 °C.

The actual setup of EATHE coupled with a solar air heating duct connected to test room is shown in Fig. 1. Experimental test set up comprises of 60 m long horizontal PVC pipe of 0.10 m diameter, buried in flat land with dry soil at a depth of 3.7 m. Inlet end of EATHE pipe is connected through a vertical pipe to a 0.75 kW, single phase, variable speed motorized blower (maximum flow rate of 0.0945 m^3/s and maximum speed of 2800 rpm). A U-shaped duct (12.2 m long having 0.0645 m^2 cross-sectional area) made of galvanized iron has been used as a solar air heating duct having top and lateral wall exposed to solar energy so as to have the receiving surface area of 3 m^2 and 2.6 m^2 respectively. Inlet of duct was connected to the outlet pipe of EATHE by means of T-socket and outlet of duct was also connected at the exit of EATHE pipe at suitable position as shown in Fig. 2. The exterior surface of the entire duct was painted black so as to absorb most of the solar radiation falling on it. Dampers were provided at the inlet and exit of solar air heating duct as well as at the exit of EATHE pipe, to regulate the flow of air. Heated air coming out of EATHE pipe can be made to flow through solar air heating duct (Mode-III) for further heating and provision was kept to supply the conditioned air directly from EATHE to test room (Mode-II) by controlling the position of dampers and valves as shown in Fig. 2. Ambient air was forced through the earth air pipe system using a centrifugal blower and air flow velocity was changed by an auto transformer (single phase, 0–270 V, 2 A maximum current, with a least count of 1 V). When the blower runs at 230 V, it corresponds to a maximum flow rate of 0.0945 m^3/s and a flow velocity of 12 m/s inside the EATHE pipe (diameter 0.1 m). However, at a certain reduced voltage, the blower supplies the air at a flow velocity of 5 m/s through EATHE pipe. The measured energy consumption of blower at this mean air velocity was 0.12 kW. The flow velocity through solar air heating duct would be different from that through EATHE pipe, but flow rate would be same through EATHE pipe as well as solar air heating duct. Some of the energy supplied to blower gets converted into heat due its inefficiency and transferred to the air passing through EATHE, which also adds to the heat imparted to the air by EATHE. Seven resistance temperature detector (RTD) (Pt-100) temperature sensors viz. T_0–T_6 were mounted at a depth of 3.7 m, 3.04 m, 2.43 m, 1.82 m, 1.21 m, 0.60 m, and 0 m, respectively, from the ground surface on inlet vertical pipe to measure soil temperatures at different depths. Nine RTD (Pt-100) temperature sensors viz. T_7–T_{15} were also inserted at the center of EATHE pipe along the length at a horizontal