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Energy metrics of a hybrid earth air heat exchanger system for summer cooling requirements

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ABSTRACT

Rapid increase in cost of power, its shortage and impact on environment, compels us to use innovative energy efficient technologies for space heating/cooling. Reduction in power consumption in vapour compression based conventional air-conditioner with air-cooled condenser is a difficult task especially in hot and humid weather conditions (Central region of India), where the summer temperature sometimes exceeds 46 °C. Power consumption of conventional air-conditioner can be reduced substantially by hybridizing it with earth air heat exchanger system. In the present research, an effort has been made to reduce the power consumption of 1.5 TR window air-conditioner by coupling with earth air heat exchanger system in three different arrangements. When entire cold air from earth air heat exchanger system is supplied to cool the air-conditioner's condenser coil, the power consumption is found to be reduced significantly in hybrid system as compared to conventional 1.5 TR window air-conditioner. The economic analysis techniques i.e. simple payback period, discounted payback period, net present value and internal rate of return validate that proposed hybrid arrangements are economically viable.

1. Introduction

Innovative approaches for space heating/cooling are being accepted and promoted to increase utilization of the renewable energy sources and reduce carbon emissions. Major portion of energy consumption in a building is utilized for space heating/cooling. Many researches reveal that building sector consumes around 40% of total world energy consumption and major portion of this approximately 32–33%, is used for space heating/cooling [1]. Combination of the active (i.e. conventional Air Conditioner (AC), electric heater, fan, etc.) and passive techniques (i.e. Ground Coupled Heat Exchanger (GCHE) systems, trombe wall, solar chimney, wind tower, phase changing materials, et.) for space heating/cooling consumes less power [2]. For space heating/cooling GCHE systems are gaining rapid acceptance. They are energy efficient, eco-friendly and consume almost no or very less energy compared to other space heating/cooling systems. They utilize geothermal storage energy and having the relative benefit over most of the other systems that they can be used for heating and cooling both. Below 3–4 m depth of earth, temperature remains always constant.

That is equivalent to the annual average temperature of its ground surface. This constant temperature is used by air/fluid passes through buried pipe, for cooling and heating the specified space [3–5]. GCHE systems are mainly two types i.e. Earth Air Heat Exchanger (EAHE) systems and Ground Coupled Heat Pumps (GSHP). Comparison between them is given in Table 1. It is concluded from Table 1 that both EAHE and GSHP systems are energy efficient. While selecting appropriate system, preference is given according to required outcome, environmental suitability, economical viability, etc. GSHP systems are more hi-tech than EAHE systems. EAHE systems are well established concept as compared to GSHP systems. Both can be effectively combined with different passive systems. Outcome of various hybrid systems with GCHE is given in Table 2.

It is observed from Table 2 that hybrid GCHE systems are able to boost the significant efficiency, limit the CO2 emission, make possible to use day and night both with economical viability. There is close agreement between experimental and simulated outcomes.

Under the climatic conditions of high summer temperatures the use of GCHE systems and its coupling with other renewable options

Abbreviation: AC, air conditioner; GCHE, ground coupled heat exchanger; COP, coefficient of performance; EAHE, earth air heat exchanger; PV, photo voltaic; SC, solar chimney; PCM, phase changing material; EPBT, energy payback time; PBP, payback period; SPBP, simple payback period; DPBP, discounted payback period; NPV, net present value; IRR, internal rate of return.

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Nomenclature

Symbols

kW	Kilo watts
kWh	Kilo watt hours
TR	Tons
kg	Kilograms
$	Dollars
Rs	Rupees
h	Hours
m	Meter
L	Length (m)
W	Width (m)
H	Height (m)
T	Temperature (°C)

Table 1
Comparison between EAHE and GSHP systems.

Parameters	EAHE systems	GSHP systems
Application	Small and medium space	Small space [6]
Cost	Low	High [7]
Buried pipe material	Anyone can be used i.e. plastic/metallic/concrete [8]	Plastic is used for water/anti-freeze and copper for refrigerant [9]
Suitability	Most suitable for summer and winter [10]	Suitable for all seasons, most suitable for monsoon [11]
Efficiency	Less [12]	More [13]

(i.e. PCM, SC etc.) cannot attain a level of thermal comfort [34,35] and able to replace the conventional residential AC systems. Therefore the number of conventional ACs is increasing exponentially. They consume huge amount of energy in buildings and pollute the environment [36]. Lots of studies related to coupling of residential AC with other renewable options (i.e. heat pipe, PCM, water cooling etc.) have been conducted to reduce the power consumption [37–39]. However, to improve cooling efficiency, reduce power consumption and environmental hazard the use of the residential ACs coupling with GCHE system is the better worthwhile option for these regions.

A very similar work done i.e. experimental analysis of a direct expansion ground coupled heat exchange system for space cooling requirements at Bhopal in India by Soni et al. [40] under the same climatic conditions, utilized the ground as heat sink for removing the heat and condensing the refrigerant of an AC system, which was flowing through buried copper tube at a depth of 3 m. Earth temperature was remained constant around 30 °C all year round. This work provided excellent performance reduced the power consumption, improved efficiency. But had some problems related to maintenance of buried copper tube and sudden underground refrigerant leakage. Combination of EAHE system with conventional AC gives immense opportunity to conserve energy and throw out the problems linked with the direct expansion ground coupled heat exchange system. Misra et al. [41] tested the hybrid EAHE system with conventional AC system for the climatic conditions of Western India, and found that electrical energy consumption decreased by 18.1% than conventional AC system. They did not cover the energy metrics, scope of CO_2 emission mitigation and comparison with direct expansion ground coupled heat exchange system under the same climatic conditions.

This paper experimentally investigates the energy metrics of a hybrid system of EAHE with conventional 1.5 TR window AC system for summer cooling requirements at Bhopal (Central India), under the climatic conditions of high summer temperatures, it every so often exceeds 46 °C. Cold air from EAHE system is utilized to reduce the power consumption of conventional AC.

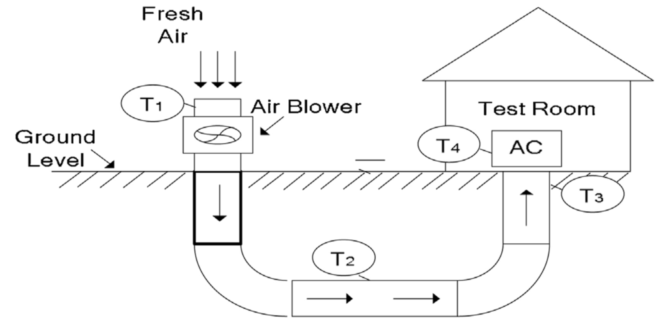

Fig. 1. Schematic diagram of hybrid EAHE system.

Fig. 2. Test room.

2. Description of experimental hybrid EAHE system

Experimental set-up of hybrid EAHE system with conventional AC is prepared at Energy Park in the campus of Laxmi Narayan College of Technology, Bhopal. The block diagram of experimental set-up of the schematic diagram of hybrid EAHE system with conventional AC is shown in Fig. 1. Different thermocouples are positioned to record the deviation in temperatures at different locations of hybrid system i.e. inlet, mid of the horizontal buried pipe at below 3 m, outlet of EAHE system and condenser of conventional AC that are represented by T_1, T_2, T_3, T_4 respectively as shown in Fig. 1.

Dimensions of test room are 2.5 m × 2.5 m × 3 m (L × W × H), it's roof and walls are made up of asbestos sheets and fully exposed to open environment. A 1.5 TR window AC with reciprocating compressor is fixed at left window of the test room at height of 1.25 m, as shown in Fig. 2.

Experimental set up consists of 11 m long cylindrical galvanized steel pipe of 0.05 m inner diameter, buried at a depth of 3 m in a plane land with black dry soil, 1.5 TR window AC with reciprocating compressor, ammeter, voltmeter, digital energy meter, 0.5 hp air blower. Total burial length of pipe is 9 m (i.e. 3 m vertical plus 3 m horizontal plus 3 m vertical). For measuring earth's temperature depth-wise 10 thermocouples at a regular distance of 0.3 m are fixed on a wooden strip, as shown in Fig. 3.