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Experimental Analysis of Ground Coupled Heat Exchange Systems: Temperature Steadiness of Ground and its Benefits

Suresh Kumar Soni
Department of Electrical Engineering,
S.V. Polytechnic College, Bhopal, India.

(Corresponding author: Suresh Kumar Soni)
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ABSTRACT: Modern building sector considers the ground also as a heat source or sink for space heating and cooling. The ground coupled heat exchanger systems are picking-up globally due to its various advantages. This experimental analysis focuses on investigation on variation in ground temperature, used as heat sink with ground coupled heat exchange systems, at different depths and seasons in Bhopal and its effect on energy savings. Two types of ground coupled heat exchange system i.e. earth air heat exchange and direct expansion ground coupled heat pump system are separately coupled with 1.5 TR conventional window air conditioner. Paper compares the performance of hybrid earth air heat exchange and direct expansion ground coupled heat pump systems under the same climatic conditions and records ground temperatures at different depth under various arrangements.

Keywords: Ground coupled heat exchanger; Heat source/sink; Ground temperature.

Abbreviations

AC	Air conditioner
DPBP	Discounted payback period
DX-GCHP	Direct expansion ground coupled heat pump
EAHE	Earth air heat exchanger
ECBC	Energy conservation building code
GCHE	Ground coupled heat exchanger
GSHP	Ground source heat pump
IRR	Internal rate of return
NPV	Net present value
PV	Present value
SPBP	Simple payback period

I. INTRODUCTION

In modern residential and commercial buildings, many countries (i.e. Japan, Spain, India, etc.) adopt renewable technologies for space heating and cooling as per guidelines of Energy Conservation Building Codes (ECBC) and building permission authorities. Renewable technologies include solar chimney, wind tower, thermal mass, appropriate orientation of building, etc. In India also, the use of ground as heat source and sink for space heating and cooling through Ground Coupled Heat Exchange (GCHE) systems have started (e.g. tourism department of Madhya Pradesh Government at Madai, Ujjain, etc.). GCHE systems absorb heat from/release to the ground [1, 2] and they are picking-up globally. They are primarily utilized for space heating/cooling, water heating, agricultural drying, bathing and swimming, etc. They decrease cooling requirement in summer and heating requirement in winter. The performance of both types of GCHE systems viz. Earth-Air Heat Exchanger (EAHE) and Ground Source Heat Pump (GSHP) systems are encouraging [3-6]. They conserve significant amount of primary energy and thus mitigate the impact on environment by reduced emissions. Previous investigations on variation in ground temperature were carried out to find out optimum depth for GCHE applications i.e. EAHE [7-15] and GSHP [16-28].

Table 1: Variation in ground temperature at different depths.

Depth of buried pipes (m)	Temperature range (°C)
1.0	31-32, Thailand [29]
1.5	31-32, India [30]
1.5	30-31, Burkina Faso [31]
2.0	30-32, India [32]
2.75	29-30, Florida [33]
3.0	28-29, Italy [34]
3.7	29-30, India [35]

It is observed from Table 1 that in the depth range of 2.75-3.7m, the ground temperature remains almost constant at around 30°C round the year and throughout the world. The variation in ground temperature under different conditions like vegetation, watering, shadowing, etc. for the same soil, was not found in the literature.

Paper experimentally records the ground temperatures at different depth under three arrangements during various seasons that have been done at Bhopal in central India and presents its benefits of stable feature in the performance of hybrid EAHE and DX-GCHP systems under the same climatic conditions.

II. EXPERIMENTAL SET-UPS

Two experimental set-ups were installed at Energy Park in the campus of Laxmi Narayan College of Technology, Bhopal to compare their performance under the same climatic conditions presented as given in Table 2.

Table 2: Experimental set-ups.

Experimental setups	Description	Remarks
1. Hybrid EAHE system	It has hybridized EAHE system with 1.5 TR conventional window Air Conditioner (AC).	Using ground as a heat sink. Refer Fig. 1 & 2.
2. Hybrid DX-GCHP system	It has hybridized DX-GCHP system with 1.5 TR conventional window AC.	Using ground as a heat sink. Refer Fig. 3.

The arrangement for measuring ground temperature was common for both the set-ups i.e. hybrid EAHE and DX-GCHP system.

Experimental set up-1: The schematic of hybrid of EAHE system with conventional AC is shown in Fig. 1.

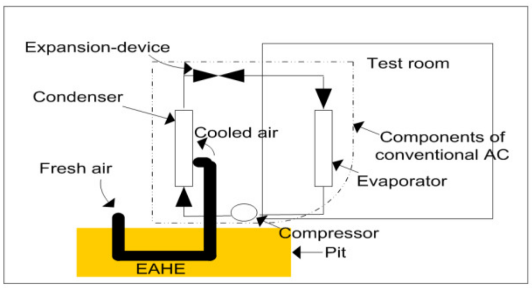

Fig. 1. Schematic of hybrid EAHE system.

Hybrid EAHE system with wooden strip for fixing thermocouples to measure earth temperatures at different depths is shown in Fig. 2. Different thermocouples (K type, nickel-chromium) were installed to record the deviation in temperatures at different locations of hybrid system i.e. inlet, mid of the horizontal buried pipe at below 3m, outlet of EAHE system and condenser of conventional AC, represented by T_1, T_2, T_3, T_4 respectively and on wooden strip, 11 thermocouples (at 0.3m regular interval, T_5- T_{15}) were mounted, as shown in Fig. 2.

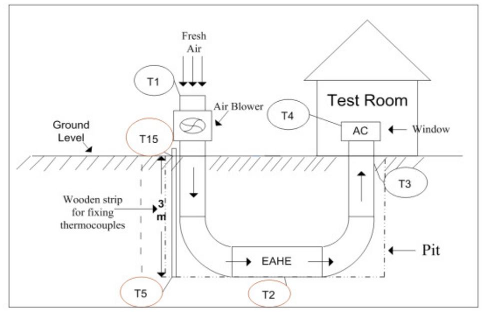

Fig. 2. EAHE system with wooden strip.

Pits arrangements: Galvanized steel pipe of EAHE and thermocouples on a wooden strip are buried (shown in Fig. 3). Pits arrangements and description are presented in Table 3.

Different modes of operation of hybrid EAHE system are given in Table 4.

Fig. 3. Buried galvanized steel pipe of EAHE and thermocouples on a wooden strip.

Table 3: Pit arrangements and description for hybrid EAHE system.

Particulars	Description	Remarks
Size of the pit	3m×3m×3m (L×W×H)	Refer Fig. 3
Thermocouples	(Type K Nickel-chromium) 11 nos. (fixed on a wooden strip at a depth intervals of 0.3m)	Refer Fig. 3
Laying of pipe	50 mm internal diameter galvanized steel pipe of EAHE, 11m long and total burial length of pipe is 9m (i.e. 3m vertical plus 3m horizontal plus 3m vertical)	Refer Fig. 3

Table 4: Different modes of operation of hybrid EAHE system.

Modes of operation	Arrangements in operating modes
Mode-I	In this arrangement only a conventional 1.5 TR window AC system works. It supplied 100% cold air to the test room. This arrangement is treated as base mode. EAHE system was kept in not working mode.
Mode-II	In this arrangement, both conventional 1.5 TR window AC and EAHE supplied their 100% cold air to test room.
Mode-III	In this arrangement, both conventional 1.5 TR window AC and EAHE were working. 100% cold air from conventional 1.5 TR window AC was being supplied to test room and 100% cold air from EAHE system was being used for cooling the condenser tubes of conventional 1.5 TR window AC

Experimental set up-2: The block diagram of experimental set-up of the hybrid DX-GCHP system with conventional AC is shown in Fig. 4. Pressure meter (P_1, P_2), R-22 rotameter (R) for 100 LPH and various thermocouples (K type, nickel-chromium) were positioned at different places of the system. To measure the variation in temperatures at different locations of DX-GCHP system i.e. outlet of evaporator, compressor, condenser, capillary narrower, denoted by T_{16}, T_{17}, T_{18}, T_{19} respectively as shown in Fig. 4 and below 3m near to buried condenser tube to measure adjoining earth's temperature (T_{20}).

Pits arrangements: Separately serpentine shaped condenser copper tubes are buried (a) horizontally (b) vertically, (shown in Fig. 5).

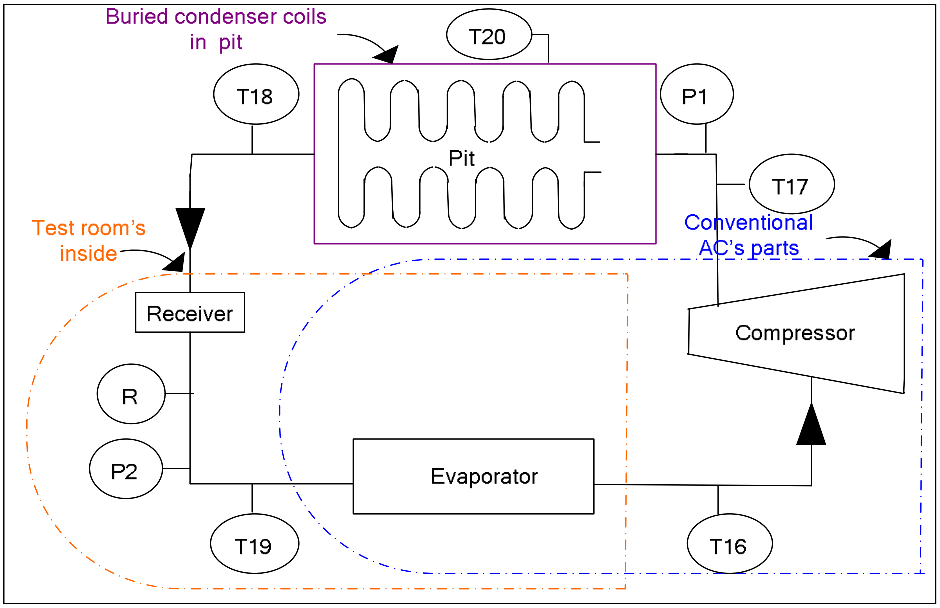

Fig. 4. Block diagram of DX-GCHP system.

(a)

(b)

Fig. 5. Serpentine shaped condenser copper tubes buried (a) horizontally (b) vertically.

The arrangement of pit and its description are given in Table 5.

Different modes of operation of hybrid DX-GCHP system are presented in Table 6.

Measurement of ground temperatures. Variation in ground temperature was measured in three different arrangements that were same for experiment 1 & 2. During performance of each arrangement the various readings were recorded from morning to evening only. Various arrangements are depicted in Table 7.

Test room & measuring arrangements: Test room and its inside measuring arrangements for hybrid EAHE and DX-GCHP (i.e. display boards, AC and portable wooden stand, presented in Table 8) are shown in Fig. 6 & 7, respectively.

Table 5: Pit arrangements and description for hybrid DX-GCHP system.

Particulars	Description	Remarks
Size of the pit	3m×3m×3m (L×W×H)	Refer Fig. 5
Laying of tubes	9.5 mm internal diameter copper tube of DX-GCHP system, two separate identical horizontally and vertically copper tubes are buried of 38m long each. Out of 38m copper tube, 29m long is buried in serpentine shape, single pass, horizontally at the bottom of the pit. Out of 38m copper tube, 35m long is fixed in serpentine shape, single pass, vertically at one side wall of the pit. Finally connected to evaporator of the window AC, 1.5m away from the pit. After laying pipe of EAHE, horizontal and vertical copper tubes of DX-GCHP system, a vertical wooden strip, pit was filled with cotton black soil.	Refer Fig. 5(a) Refer Fig. 5(b)

Table 6: Different modes of operation of hybrid DX-GCHP system.

Modes of operation	Arrangements in operating modes
Mode-I	Only the conventional window AC supplies the conditioned air to the test room and DX-GCHP system is not functional. This mode is treated as base mode.
Mode-II	AC's condenser coil is separated and refrigerant flows through buried horizontal copper tubes. Thus only the horizontal DX-GCHP system supplies the conditioned air to the test room.
Mode-III	AC's condenser is separated and refrigerant flows through buried vertical copper tubes. Thus only the vertical DX-GCHP system supplies the conditioned air to the test room.

Table 7: Arrangements for measuring ground temperatures.

Arrangement-I	Arrangement-II	Arrangement-III
No modification was done with ground surface. The pit was filled with soil and maintained dry.	Ground surface and soil of the pit were maintained wet.	Ground surface was fully covered by synthetic grass, for observing shadowing effects. Ground surface and soil were maintained dry.

Fig. 6. Test room.

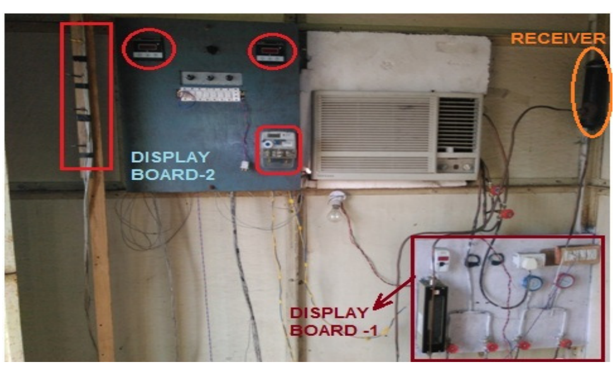

Fig. 7. Display boards 1 & 2, AC and portable wooden stand inside the test room.

Table 8: Summary of measuring arrangements.

Particulars		Description	Remarks
Test room	Size	2.5m×2.5m×3m (L×W×H)	Refer Fig. 6
	Materials	Room top and walls are made-up of asbestos sheets	Refer Fig. 6
	Floor	Cemented	Refer Fig. 6
	Door (1 no.)	0.75 m x 1.75 m (W x H)	Refer Fig. 6
	Windows (2 nos.)	0.5m×0.5m (W×H), at a height of 1.25 m	Refer Fig. 6
Display board	1	Ammeter, voltmeter, pressure gauge meter, R-22 rotameter (R) for 100 LPH	Refer Fig. 7
	2	Digital energy meter and digital temperature indicator	Refer Fig. 7
Receiver		A receiver is fitted before evaporator to control the back returning pressure of the refrigerant, because horizontal and vertical buried copper tubes have lesser bends than conventional AC's condenser copper tubes	Refer Fig. 7
Air temperature inside the room		A movable wooden stand is made with the arrangement of fixing 10 thermocouples at 0.2m interval, for taking temperature of air, inside of the room equipped with test setup	7

III. MEASUREMENTS OF GROUND TEMPERATURES

Tests were performed during rainy, winter and summer seasons. Measurements were recorded through digital indicator mounted on display board-2 (shown in Fig. 7). The earth's temperature of the soil (with soil filled-up in the pit) was recorded through buried thermocouples at 11 locations (T_5-T_{15}) in different seasons (i.e. rainy, winter, summer). Earth's temperature recorded on different dates for arrangements-I, II and III are given in Table 9.

The monthly average of earth temperatures recorded for Arrangement-I are given in Table 10.

Average earth temperatures recorded for Arrangement-II are given in Table 11.

Table 9: Dates of recording the earth's temperatures at 10 AM, 2 PM and 5 PM.

Month	Arrangement-I (Dates)	Arrangement-II (Dates)	Arrangement-III (Dates)
September 2017	5, 6 and 9	15, 16 and 17	25, 26 and 27
January 2018	5, 6 and 8	15, 16 and 17	25, 26 and 27
March 2018	5, 6 and 7	12, 13 and 14	22, 23 and 24
May 2018	5, 6 and 9	11, 12 and 13	21, 22 and 23

Table 10: Arrangement-I: Average earth temperatures recorded up to 3m depth.

Depth from ground surface (m)	Earth temperature			
	September 2017 (°C)	January 2018 (°C)	March 2018 (°C)	May 2018 (°C)
0.00	35	30	37	40
0.30	33	30	35	36
0.60	32	31	33	34
0.90	32	31	32	33
1.20	32	31	32	32
1.50	31	31	31	32
1.80	31	31	31	32
2.10	31	31	31	31
2.40	30	30	31	31
2.70	30	30	30	30
3.00	30	29	30	30

Table 11: Arrangement-II: Average earth temperatures recorded up to 3m depth.

Depth from ground surface (m)	Earth temperature			
	September 2017 (°C)	January 2018 (°C)	March 2018 (°C)	May 2018 (°C)
0.00	32	27	34	35
0.30	32	27	33	34
0.60	31	27	32	33
0.90	31	28	31	32
1.20	31	28	31	32
1.50	31	28	31	32
1.80	31	28	31	31
2.10	31	28	31	31
2.40	30	28	31	31
2.70	29	28	29	29
3.00	28	28	29	29

Average earth temperatures recorded for Arrangement-III are given in Table 12.

It is observed from Table 10, 11 and 12 that average earth temperatures at a depth of 3m temperature remain reasonably constant at about 30°C round the year. Hence a depth of 3m was decided for burying pipe & tubes of EAHE and DX-GCHP system, respectively (Fig. 2 & 5).

It is observed that earth's temperature could be slightly reduced by watering the pit's surface to maintain wetness in pit's soil. It is observed from Table 10, 11 and 12 that results of arrangement-II are slightly better i.e. around 6-7% lesser temperature at depth 3m than arrangement-I and III. Here it could be managed by maintaining garden above the pit and in area surrounding the test room. Average earth's temperature in arrangements-I, II, III are presented in the months of September 2017, January 2018, March 2018 and May 2018 in Fig. 8 (a), (b), (c) and (d) respectively.

Table 12: Arrangement-III: Average earth temperatures recorded up to 3m depth.

Depth from ground surface (m)	Earth temperature			
	September 2017 (°C)	January 2018 (°C)	March 2017 (°C)	May 2018 (°C)
0.00	33	29	35	36
0.30	33	29	34	36
0.60	32	30	33	34
0.90	32	30	32	33
1.20	32	31	32	32
1.50	31	31	31	32
1.80	31	31	31	32
2.10	31	30	31	31
2.40	30	30	31	31
2.70	30	30	30	30
3.00	30	29	30	30

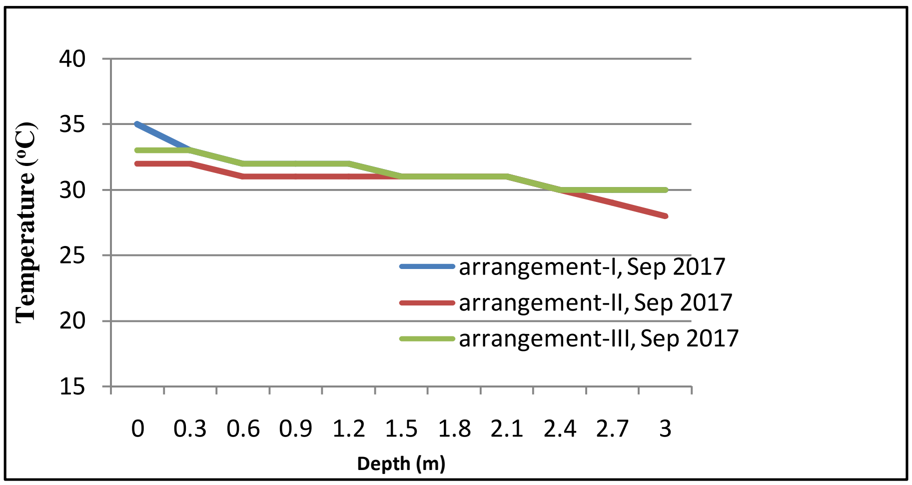

Fig. 8(a) Variation in earth's temperature in September 2017.

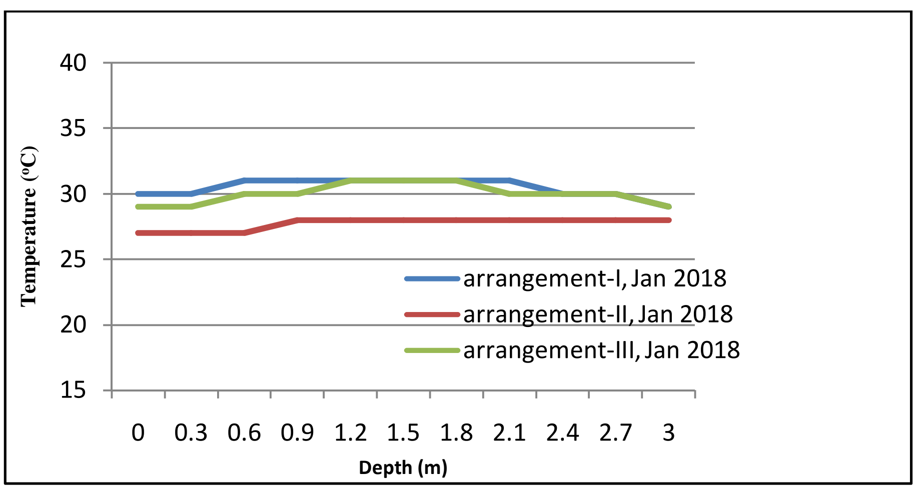

Fig. 8(b) Variation in earth's temperature in January 2018.

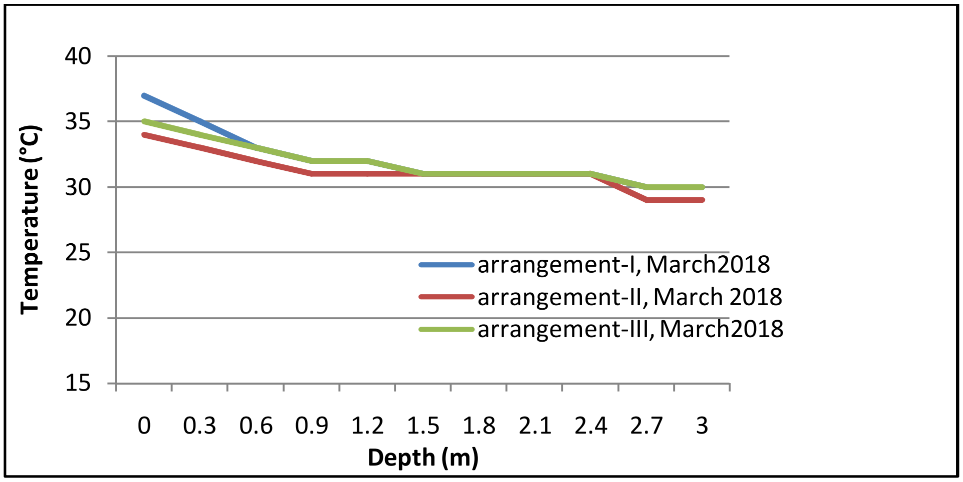

Fig. 8(c). Variation in earth's temperature in March 2018.

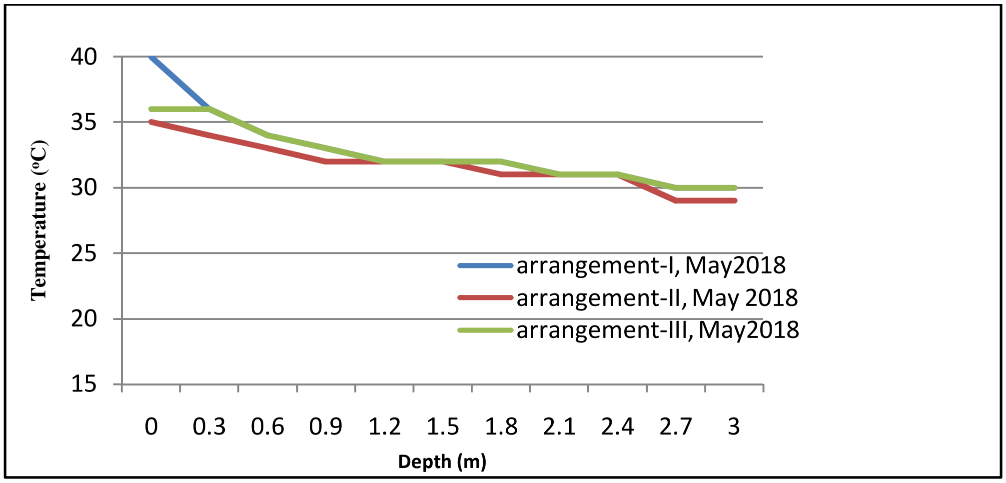

Fig. 8(d). Variation in earth's temperature in May 2018.

It is found from Fig. 8 (a), (b), (c) and (d) that underground depth at 3m than the ground surface temperature of earth remains stable at about 30°C round the year. This concept is more appropriate where ground surface temperature fluctuates in high range [3-6].

IV. MEASUREMENT OF TEMPERATURES ADJOINING BURIED COPPER TUBES, OTHER LOCATIONS AND PRESSURES

Temperature and pressure at different points T_{16}-T_{20} and P_1, P_2 respectively, as shown in Fig. 4, are recorded for summer and rainy season for mode I, II and III for hybrid DX-GCHP system. Average values of temperature and pressure variations for different modes are presented in Table 13.

Table 13: Average temperature and pressure at different points T_{16}-T_{20} and P_1, P_2.

Time (h)	Mode I						Mode II, III	
	T_{16} (°C)	T_{17} (°C)	T_{18} (°C)	T_{19} (°C)	P_1 (Suction side) (psi)	P_2 (Discharge side) (psi)	T_{20} (°C) Summer	Rainy
9	26	65	28	16	70	235	30	29
10	26	75	29	16	72	235	30	29
11	27	85	29	18	72	235	30	29
12	28	90	31	20	75	235	31	29
13	30	101	34	21	75	236	31	29
14	32	101	35	22	75	241	31.5	29.5
15	30	108	36	23	80	240	31.5	29.5
16	29	110	35	22	80	240	31.5	29.5
17	28	107	35	22	80	240	32	29
18	28	105	35	20	85	242	32	29
19	27.1	105	34	19	85	244	31.5	29
20	27	103	34	18	85	245	31	29

It is observed from Table 13 that values of T_{16}-T_{19} are almost same for summer and rainy season for mode-I. However adjoining soil temperature of tube (i.e. T_{20}) is higher in summer than rainy season, due to wetness of soil. It was recorded that values of T_{18} and T_{19} for mode II and III were approximately 3-4^{o}C and 1^{o}C respectively lower than mode-I. Almost same results were found in hybrid EAHE system for mode II and III, regarding T_{18} and T_{19}, which results in increased refrigeration effect by around 10%.

V. BENEFITS OF TEMPERATURE STEADINESS OF GROUND

It has been experimentally found that stable feature of ground temperature has got several benefits, presented in Table 14.

Table 14: Benefits of temperature steadiness of ground.

Hybrid systems	Important findings
Hybrid EAHE systems	Experimental results conclude that electrical energy consumption in mode-II, III (refer Table 4) of hybrid EAHE system with 1.5 TR window AC can be reduced by 6.7% and 11.07%, respectively as compared to conventional 1.5 TR window AC at 11 m/s air flow velocity during rainy season. Proper wetness of earth increases the efficiency of EAHE system. During summer season power consumption is increased by 5.56% and 5.6% in mode-II and III, respectively. Lowering the air flow velocity up to certain limit gives positive impact on power consumption of AC. Air temperature decreases more in the initial length of the buried pipe [36].
Hybrid DX-GCHP system	Hybrid DX-GCHP system reduces electrical energy by reducing compressor's load of 1.5 TR window AC. Electrical energy consumption as compared to conventional 1.5 TR window AC is reduced by 11.25% and 14.68% during rainy season in horizontal and vertical configurations, respectively. Experimental results of hybrid DX-GCHP system show that efficiency is obtained better during rainy season than in summer season. During summer season power consumption is increased by 3.12% and 3.41% in horizontal and vertical configuration, respectively [37].

It can be concluded from Table 14 that both the systems are effective and environment friendly. Hybrid DX-GCHP system is more efficient than hybrid EAHE system, but costlier and complicated. Preference could be given in selection of hybrid GCHE systems according to their efficiency, economic and environment viability.

VI. ECONOMIC ANALYSIS

Economic analysis is very useful for evaluating the validity of an investment business and it ranks the projects according to financial benefits. There are a number of economic analysis techniques. Broad classification is presented in Fig. 9.

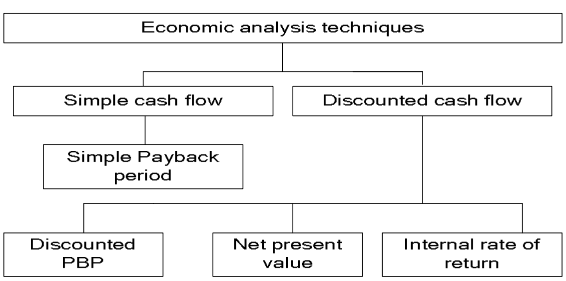

Fig. 9. Classification of economic analysis techniques.

Simple Pay Back Period (SPBP) is the time period in which the project generates the required cash to recoup the investment. Discounted Pay Back Period (DPBP) is a type of discounted cash flow methods i.e. considers time value of money. Other discounted cash flow methods are Net Present Value (NPV), Internal Rate of Return (IRR). NPV is an algebraic summation of Present Values (PVs) of all cash inflows and cash outflows over a life time period of project. Equation for calculating NPV is as follows:

$$NPV=\sum_{t=0}^{n} CFt/(1+K)^{t} \quad (1)$$

Where CF_t, cash flow occurring at the end of the year t; n, life of the project; K, discount rate.

Positive NPV is accepted and IRR is the rate at which NPV equals to zero [38]. Simple Pay Back Period (SPBP) and Discounted PBP (DPBP) are preferred for short term planning. NPV and IRR are used for evaluating projects for long term planning and consider full life time returns of the project. Results of economic analysis using ground as heat sink with ground coupled heat exchange systems are presented in Table 15.

Table 15: Economic analysis of set up I (i.e. hybrid EAHE system) and II (i.e. hybrid DX-GCHP system).

Techniques	Hybrid EAHE system [36]	Hybrid DX-GCHP system [37]
SPBP (years)	1.2	1.37
DPBP (years)	2.9	1.56
NPV (%)	10	11.21
IRR (%)	54.18	72.05

It is observed from Table 15 that economic analysis of first experimental set-up (i.e. hybrid EAHE system) reflects that the Simple Pay Back Period (SPBP) and Discounted Pay Back Period (DPBP) work out to be 1.2 and 2.9 years respectively. Net Present Value (NPV) of total life time cash outflows is 10% lower as compared to conventional 1.5 TR window AC and value of Internal Rate of Return (IRR) is high (i.e. 54.18%).

Economic analysis of second experimental set up (i.e. hybrid DX-GCHP system) reveals that SPBP and DPBP are less than two years. NPV of total life time cash outflows is 11.21% lower as compared to conventional 1.5 TR window AC and IRR is favorable and very high is 72.05%.

VII. CONCLUSION

The experiments were carried out to record the ground temperatures at different depths for different arrangements and their impact on performance of hybrid EAHE and DX-GCHP systems under the same climatic conditions. It was found that at a depth of 3m below ground surface, temperature remained stable around 30^{o}C throughout the year. The electrical energy consumption in hybrid EAHE system with 1.5 TR window AC was reduced by 11.07% as compared to conventional 1.5 TR window AC during rainy season but increased by 5.6% during summer. In hybrid DX-GCHP system as compared to conventional 1.5 TR window AC, power requirement was decreased by 14.68% during rainy season and increased by 3.41% in summer. The economic analysis parameters SPBP, DPBP, NPV and IRR were 1.2, 2.9 years, 10% positive, and 54.18%, respectively for the hybrid EAHE system. Same analysis for hybrid DX-GCHP system resulted in SPBP and DPBP to be less than 2 years whereas NPV and IRR were 11.21% positive and very high 72.05%, respectively. Economic analysis reflects that all economic tools are favorable. Refrigeration effect of 1.5 TR window AC was increased by around 10%, it could become possible due to hybridization of air conditioner with EAHE and DX-GCHP.

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