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IMPLEMENTATION OF AN ECO-FRIENDLY EARTH-TO-AIR HEAT EXCHANGER FOR COOLING EFFECT USING RENEWABLE ENERGY SOURCES

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Abstract*- Nowadays, the application of air cooling is rapidly increasing with the human comfort level, especially in tropical regions. However, typical air conditioners for cooling purposes operate mostly by fossil-fuel-based energy and the majority of these release harmful substances that are detrimental to the environment. This study aims to design and implement an eco-friendly and cost-effective air cooler using environment-friendly as well as an available energy source. Therefore, to execute this purpose a preliminary and improved design of open-loop earth-to-air heat exchanger is proposed and experimentally implemented in summer. The main differences between the preliminary and the improved design are the construction materials and depth from sea level. The underground soil temperature is measured in the project area and the whole system is powered by geothermal and solar energy. The results show about 6 to 8.5°C temperature reduction from ambient temperature for improved design; consequently, the improved design is found to be more effective.*

Keywords: *Air cooler, Earth-to-air heat exchangers, Eco-friendly, Geothermal and Temperature*

1. INTRODUCTION

Cooling process is a physical operation in which heat is removed from process fluids or solids using various methods which are implemented via a cooling system. Various cooling systems are currently available worldwide but majority of them uses fossil fuel based energy and has a detrimental effect on the environment. Despite energy acts as a primary catalyst in developing the technological, industrial, economic sectors within the society, rapid developments of industry and population growth have led to a surge in the demand in our country. So it is imperative and urgent to find out the alternative and clean sources of energy to replace the conventional fuels which has a limited source and adverse effect on the environment.

Sustainable development is not possible without sustainable energy and renewable Energy is a key to sustainable development. Geothermal energy is a clean, environment friendly, sustainable and reliable source of energy and its supply is independent of season and global energy market dynamics. So, the wise implementation and use of geothermal energy could meet our increasing energy demand and play a vital role in mitigating the adverse effect on the environment.

Geothermal energy can be an interesting alternative concerning the production of energy for air conditioning for both industrial and domestic use. Typical vapor compression machine uses more energy and emits harmful substances, which is detrimental to the environment. So, it is necessary to find an eco-friendly substitute, and here, geothermal energy could be a promising solution.

Existing air coolers are mostly commercially available for well-off people, particularly living in electricity grid-connected area. Such commercially available systems cannot be an alternative to the remote area or low-income people. Other non-commercial devices either primarily requires a pre-cooling medium or other sources of energy. Again, these devices cannot replace the existing commercial systems. Moreover, very little academic lab-based research projects had recently been conducted for a possible alternative to the remote areas. Such conceptual projects had neither any physical testing or sample data nor performance evaluation of the system, thus making these attempts ineffective. As such, this project aims to introduce an improved air cooling system for rural and remote places, without any grid-connected electricity by using natural resources only. To this end, this eco-friendly system will be designed, manufactured as prototype, and tested performance with for its effectiveness.

Several researches have been carried out in this field. Minichiello et al. [1] found that best energy performances can be obtained for wet soil and cold climate. Bojic et al. [2] investigated the influence of the season, soil thermal conductivity and pipe spacing on energy transfer from the soil to the two pipe earth to air heat exchanger. Singh et al. [3] focused on air conditioning with open loop, zigzag pattern, and rectangular earth to air tunnel system buried at a depth of 10 feet. Their result showed a 13°C reduction from ambient temperature in summer and 5°C reduction in winter. Patil et al. [4] conducted a comprehensive study on a geothermal earth-to-air system and showed the effect of different parameters on its performance. They also showed that the velocity range of 2-5 m/s and soil depth of 1.5 to 2 meters are favorable for a better performance. Sharan et al. [5] investigated the performance of a closed loop, circular pipe earth to air heat exchanger buried 3.5m beneath the ground. This system yields a 7°C reduction from ambient temperature during summer. Bellos et al. [6] in their study proposed an eco-friendly refrigerant, R152a for conventional air conditioning. Bisoniya et al. [7] done an analytical and experimental study on earth to air heat exchanger. Their study focuses on the potential of geothermal energy as a green, clean and unlimited source of energy. Kaushal [8] did a comprehensive experimental study on an earth-to-air heat exchanger and showed the effect of different parameters in both Summer and Winter. He found out that air velocity has a crucial effect on its performance, but the effect of pipe material is negligible.

Beside these experimental investigations some numerical studies are also available. Sardana et al. [9] numerically studied the effects of construction material, depth, air velocity, pipe length on the performance of earth-to-air heat exchanger using Finite Volume Method. They found that depth from earth, air velocity, pipe length have significant effects, whereas the effect of pipe material is negligible. Madane et al. [10] carried out a CFD analysis of an earth to air heat exchanger and analyzed its performance.

Off closer relevance to the current project is WindChill Fridge [11], which was a very preliminary student project tested in Canadian cool environment. They, however, did not present any physical data in support of the effectiveness of the system, including ambient temperature. Later, Ahmed [12] showed that the original Windchill design is not effective for warm environment, such as Asia and almost no temperature variation was observed from the original design. He then modified the system and was able to lower the ambient temperature (30-35°C) by about 3°C. Modifications include: use of two dc fan (one in the evaporation chamber and the other in refrigeration chamber) to ensure constant air flow, use of filter in the air inlets to ensure clean air and reduction of pipe diameters similar to expansion valve in a refrigerator. It appears that further testing and modifications may be required for better effectiveness of the system.

2. THEORITICAL ASPECTS

2.1 Ecofriendly Cooling System

Eco-friendly cooling systems may be seen in various ways, but following two are most common in heating or cooling applications:

i. Evaporative Air Cooler
ii. Geothermal System

An **evaporative cooler** is a device that cools air through the evaporation of water. Evaporative cooling differs from typical air conditioning systems, which use vapor-compression or absorption refrigeration cycles. Evaporative cooling works by exploiting water's large enthalpy of vaporization. The temperature of dry air is allowed to drop significantly through the phase transition of liquid water to water vapor (evaporation). The advantage of it is that the system can cool air using much less energy than refrigeration. In extremely dry climates, evaporative cooling of air has the added benefit of conditioning the air with more moisture for the comfort of building occupants. [13].

Geothermal systems, one of the most recent innovations in eco-friendly heating and cooling systems, are growing in popularity in both businesses and homes. Since the earth absorbs nearly half of the sun's energy, a geothermal system puts that unused energy to use, making it one of the most efficient and cost-effective ways to heat and cool a home. The geothermal energy system uses loop pipes, which are installed below the ground. The pipes carry a water solution that absorbs the earth's heat, which is then released where you need it most. During cold winter months, the absorbed heat is transferred through the geothermal system into your home. The heated water solution condenses, circulating the heated air to provide the whole house with warmth. For cool air during the summer, the process is reversed. The unwanted heat from within your house is absorbed through the water solution and taken back underground, leaving you with a comfortable living space [14].

2.2 EARTH-TO-AIR HEAT EXCHANGER

In this current era, there is a strong need to consider alternate and eco-friendly ways for thermal comfort in dwellings and commercial buildings, and to minimize hazardous effects on the environment. An earth air pipe heat exchanger would be one of the many alternate solutions. An earth air pipe heat exchanger is a long metal or plastic pipe, which is buried a few meters deep that utilizes the ground as a heat sink for cooling or heating purposes. As the temperature few feet below the ground is nearly constant, it substantially reduces ambient air temperature fluctuations. Therefore, it provides space conditioning throughout the year, with the incoming air being heated in the winter and cooled in the summer. It is best suited to mechanically ventilated buildings with a moderate cooling demand, located in climates with a large temperature differential between summer and winter and between day and night. It can either be an open or closed-loop system.

3. RESEARCH METHODOLOGY

3.1 Experimental Setup

In order to achieve the above objectives following methodology is systematically performed.

3.1.1 Preliminary Design

Two setups are designed for implementing prototypes so as to study improvements of the previously modified cooler design by Ahmed [12]. The copper tubes are placed at about 1 ft. below the soil surface, similar to the distance adopted by Ahmed [12]. The prototypes (as shown below) will help to take physical data to assess their effectiveness. Both setups are different in the sense that the first setup has no evaporation chamber whereas tube dimensions are constant in both cases. This test will ensure the effectiveness of the evaporation chamber.

Setup-1 (Without Evaporation Chamber)

In this setup (Fig. 1), four different diameter copper pipes are used, namely 5/8, 3/8, 5/16 and 1/4 in. 5/8 in pipe is bended as a U-shaped, which is joined with U-shaped 3/8 in pipe. After that, it is joined with U-shaped 5/16 in pipe which is connected to the cooling unit via U-shaped 1/4 in pipe. A 4 ft. long PVC pipe is attached with the 5/8 in in front of the setup, and a funnel is attached with the PVC pipe to draw air into the pipe. In the cooling unit, a CPU Cooler fan run by power from solar panel is attached with body to ensure air flow.

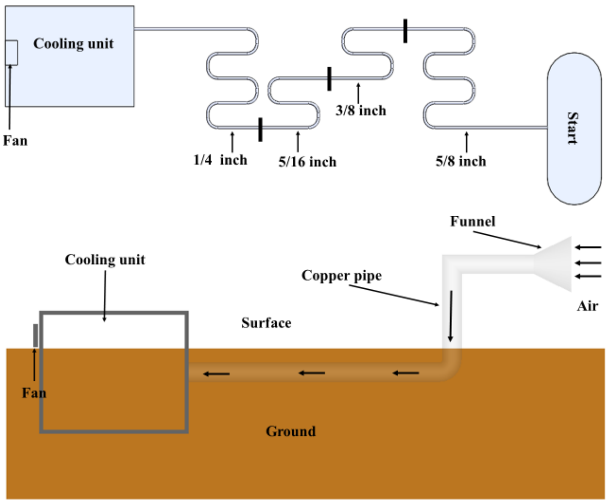

Fig.1: Pipe dimensions and relative positions of the components for Setup-1

Fig.2: Implementation of setup-1 at KUET premises

Setup-2 (With Evaporation Chamber)

Similar to the Setup-1, four different diameters copper pipes are used, namely, 5/8, 3/8, 1/2 and 1/4 in, that is shown in Fig. 3. U-shaped 5/8 in pipe is joined with U-shaped 1/2 in pipe and the pipe is allowed to rise then above the ground to connect with the evaporation chamber where U-shaped 3/8 in copper pipe is immersed in the water. It is then joined with 1/4 in coil which acts as expansion device, before joining with 3/8 in again and goes to the cooling unit. PVC pipe, funnel and CPU cooler fan are attached to the system similarly to the Setup-1.

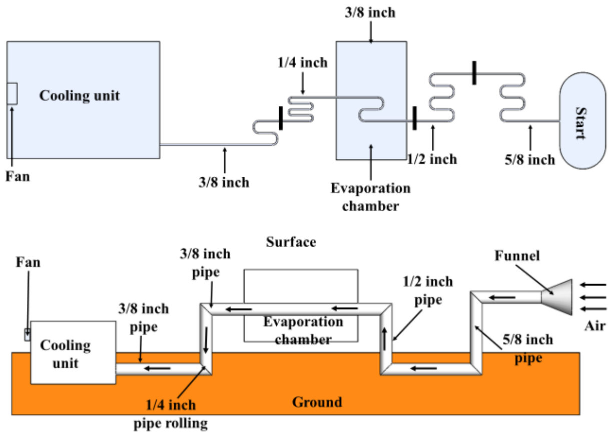

Fig.3: Pipe dimensions and relative positions of the components for Setup-2

Fig.4: Implementation of setup-2 at KUET premises

3.1.2 Improved Design

This system consists of 22m long 1 inch PVC pipes joined in U shapes [Fig. 5(a)] and with five horizontal loops at a depth of 1m with dry soil. One end of the pipe arrangement is connected with the air inlet unit and another end is connected with the cooling unit. Air is supplied in the pipes at a rate of 2.3m/s using a dc blower in the air inlet unit. The cooling unit [Fig. 5(b)] consists of a cooling chamber, a Peltier module, two cooling fan, a water block, two heatsinks, a dc pump and a water reservoir. The Peltier module is introduced to further cool the conditioned air.

First, air is forced into the pipes using the blower. The soil temperature lies below the atmospheric temperature in Summer. So, air travels through the pipe arrangement and gives up heat to the soil. Then, the air temperature almost reaches the soil temperature. Now this air travels through the cooling chamber. Then the air comes into contact with the cold face of the Peltier module before leaving the cooling chamber. A water block, heat sink and a fan is used to cool the hot face of the Peltier module. The pump circulates water through the water block to carry off heat from the hot surface of the Peltier module.

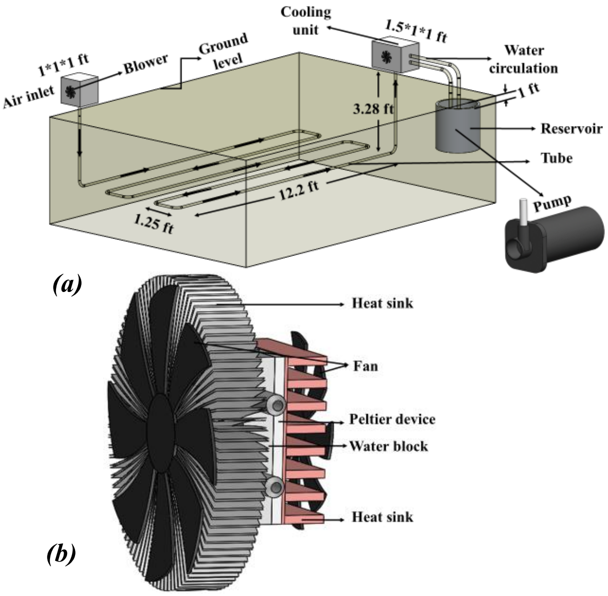

Fig.5: (a) Schematic view of improved design. (b) Magnified view of the Peltier module unit (inside cooling unit)

3.1.3 Underground Temperature Measurement

There was no temperature data under the ground available on the premises where the prototypes were implemented. In fact, such data is scarce even in the country. The temperature distribution of soil under the ground is essential. In this regard, the soil is dug 10 ft. down the ground, and 10 thermocouples are placed at each ft. down to track the soil temperature.

3.2 Required Raw Materials and Machining Operations

Although a range of raw materials were used in this project, major components are:

i. Different sized copper pipe (3/4, 5/8, 1/2, 3/8, 5/16 and 1/4-inch diameter)
ii. Plexi glass
iii. CPU cooling fan
iv. PVC pipe
v. Solar panel
vi. Copper wire
vii. Thermoelectric cooler
viii. CPU cooler with heat sink
ix. Temperature controller
x. Thermocouple
xi. 12v dc pump

After purchasing raw materials, few manufacturing or machining operations were needed. These operations were performed both commercial workshops and KUET workshop, where appropriate.

4. RESULTS AND DISCUSSION

Experimental analysis of an earth-to-air heat exchanger has been performed and variation of velocities for a range of copper pipe dimensions, temperature reductions for different setups and underground soil temperature distributions normal to the surface has been measured.

4.1 Preliminary Design

Figure 6 reveals the temperature calibration curve for the used temperature measuring device with the standard device available at KUET. The result highlights that the newly purchased temperature measuring device fairly agrees with our standard thermometer and the instrument is found to be reliable.

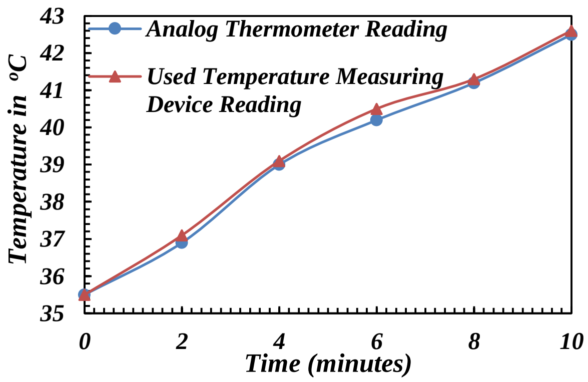

Fig.6: Data comparison of the used temperature recorder with a standard.

The cooling effectiveness of the system is now analyzed via temperature measurement in the environment and inside the cooling unit. The reading for different times of a day over three-day period is presented in Table 1. It appears that about 3°C temperature reduction from ambient was found from this system.

Table 1: Temperature measurements at the cooling unit of the eco-friendly cooling system

Obs No.	Time	T_0°C	T_E °C	T_C °C
1	10:30 am 17/10/2017	34.1	30.9	31.0
2	04:30 pm 17/10/2017	33.6	29.8	30.0
3	10:30 am 18/10/2017	32.9	30.2	30.3
4	04:30 pm 18/10/2017	33.0	30.0	30.3
5	12:20 pm 19/10/2017	30.1	27.8	28.3

The effect of varying tube diameter on the air velocity and flow rate is presented in Table 2. It is evident that air velocity increases with the decrease of tube diameters, as expected. However, the velocity increment rete is not the same as the tube diameter decrement, and in fact, much lower than the theoretical velocity. This discrepancy is attributed to the significant losses in tubes and tube joints, where larger diameter tubes are joined together with sequentially smaller diameter tubes. So, the tube loss enhances from increased tube length and number of joints. Additionally, providing uniform flow rates at tube inlet through a fan was also challenging and partly contributes to this discrepancy. In contrast, air flow rates are found to be higher for larger diameter tubes regardless of the fan position. This reduction in flow rates for smaller diameter tubes are due to the increasing blockages associated with tube joints, that inhibits the air flow. Temperatures at the tube outlets are almost similar to the ambient.

Table 2: Data for air velocity and flow rate through varying diameter tubes

Tube Diameter	Velocity (m/s)	Distance of funnel from the Fan	Flow rate X 10^{-4} (m^3/s)
(3/4)”	3.50	1’	9.975
	3.30	2’	9.406
	3.18	3’	9.064
(5/8)”	2.56	1’	5.379
	2.33	2’	5.264
	2.21	3’	5.056
(3/8)”	2.89	1’	1.789
	2.76	2’	1.717
	2.69	3’	1.689
(5/16)”	3.34	1’	1.559
	3.54	2’	1.524
	3.67	3’	1.494
(1/4)”	4.26	1’	1.816
	4.17	2’	1.772
	4.06	3’	1.707

Table 3 exhibits the temperature data for two setups discussed in the section 3.1.1. It appears that although the use of evaporation chamber might be useful in cold countries like Canada for WindChill Fridge [11], notwithstanding, for warm countries it has no impact at all in terms of temperature reduction. Moreover, temperature increase is observed for the addition of evaporation chamber (Setup-2). As such, it can be concluded that evaporation chamber in this kind of eco-friendly cooler is not necessary as it associates temperature rise and additional cost. Significant temperature reduction is not found as reasonably expected for the Setup-1, since the primary objective of this test was to check the adequacy of the use of evaporation chamber.

Table 3: Temperature data for Setup-1, T_1 and Setup-2, T_2 (inside cooling unit)

Date	T_0 °C	T_1 °C	T_2 °C
22/11/18	28.5	27.0	27.5
25/11/18	29.0	26.5	27.5
26/11/18	29.0	25.0	26.0
27/11/18	29.0	25.5	26.0

4.2 Improved Design

Though the designs discussed in sections 3.1.1 are ecofriendly, albeit, temperature reduction was found to be minimal i.e. within 3°C. In order to have a better cooling effectiveness, a new design is proposed in the section 3.1.2. The result of this new proposed design is presented in Table 4. The data is collected at different times to test its effectiveness. It can be resolved that this design is able to reduce the air temperature by 6-8.5°C. The cooling unit temperature is nearly equal to the soil temperature around 3 feet below the ground surface, which is encouraging.

Table 4: Experimental data for an ecofriendly cooling system for improved design

Date	Time a.m.	T_0 ^{0}C	T_C ^{0}C	T_S ^{0}C	ΔT ^{0}C
19/06/19	10.00	37.00	31	29	6.00
23/06/19	09.35	38.00	30	29	8.00
23/06/19	10.25	41.00	34	33	7.00
25/06/19	10.00	40.50	32	31	8.50
25/06/19	11.00	42.00	34	33	8.00

4.3 Underground Soil Temperature Distribution

Finally, underground soil temperature distribution across soil depth is depicted in Fig. 8. The data presented here are averaged over the month, as a representative in a particular month. It is clearly seen that soil temperature is nearly constant (within 1°C variation) up to 4 feet down. In winter, the temperature then slightly increases in the next 3 feet, and in summer, the temperature decreases slightly for the same height down. From 8 feet, the soil temperature goes down, regardless of the season. As expected, the soil temperature is higher in summer and lower in winter, and this tendency up to the 5 feet. The variations become minimal as the distance down the ground increases and at 10 feet the temperature becomes almost same, irrespective of the month.

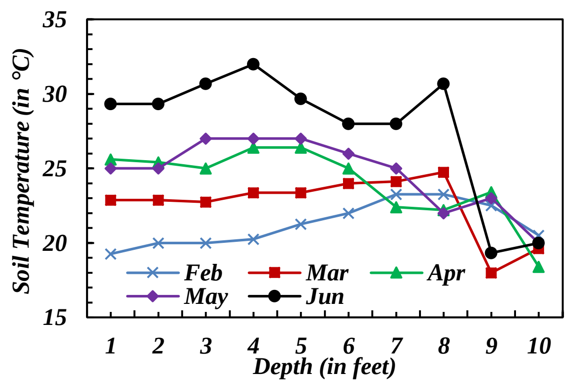

Fig.7: Underground soil temperature distribution against depth.

5. CONCLUSION

Improvements of an ecofriendly air cooler and two other variations are experimentally investigated in this project. In this regard, an improved open loop earth- to-air heat exchanger is also examined for its effectiveness over others. Moreover, underground soil temperature distribution was sought. The results are summarized as follows:

- WindChill Fridge [11] is not effective at all in warm countries, such as Bangladesh. Moreover, evaporation process of the ecofriendly cooler is found to be unnecessary.
- Earth-to-air heat exchanger that uses Peltier module is found to be significantly effective and reduce ambient temperature by 6 to 8.5°C. The increased heat transfer rate of hot side of Peltier module would yield better result.
- Soil temperature is found to be nearly constant (within 1°C variation) up to 4 feet down. In winter, the temperature then slightly increases in the next 3 feet, however, in summer, the temperature decreases slightly for the same height down. The temperature variation become minimal with the enhancement of underground distance and at 10 feet the temperature becomes almost same, irrespective of the month.

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8. NOMENCLATURE

Symbol	Meaning	Unit
T_0	Ambient Temperature	^0C
T_C	Cooling unit (Box) temperature	
T_S	Soil temperature,	
ΔT	$T_0 - T_c$	
T_E	Exhaust temperature	