*Performance Analysis of Underground Duct for room environment control*

*A Thesis*

*submitted in partial fulfillment of the requirement for the award of degree of*

Masters in Thermal Engineering

By

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July-2013

## DECLARATION

I hereby declare that the thesis entitled "Performance Analysis of Underground Duct for room environment control" submitted in the partial fulfillment of Master of Engineering in Mechanical (Thermal) Engineering to Thapar University, Patiala, is a record of candidate's own work carried out by him under our supervision and guidance. This matter embodied in this report has not been submitted in part or full to any other university or institute for the award of any degree.

(Pawanjot Singh)

This is to certify that above declaration made by the student concerned is correct to the best of my knowledge & belief.

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## ACKNOWLEDGEMENT

With deep sense of gratitude I express my sincere thanks to my guides, *Mr. Sumeet Sharma* and *Dr. T.K. JINDAL* for their valuable guidance, proper advice and constant encouragement during my thesis work.

I also feel very much obliged to *Dr. Ajay Batish*, Professor & Head, of Mechanical Engineering Department.

I am also very thankful to my friends for their cooperation.

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# ABSTRACT

Earth-pipe-air heat exchanger systems can be used to reduce the cooling load of buildings in summer. In a developing country like India, there is a huge gap in demand and supply of electricity and rising electricity prices have forced us to look for cheaper and cleaner alternative. Our objective can be met by the use of ground heat exchangers and the system is very simple which works by moving the heat from the house into the earth during hot weather. Measurements show that the ground temperature below a certain depth remains relatively constant throughout the year. Experimental investigations were done on the experimental set up in PEC University of Technology, Chandigarh. Effects of the operating parameters i.e air velocity and temperature on the thermal performance of horizontal ground heat exchanger are studied. For the pipe of 13.6 m length and 0.15 m diameter, temperature rise of $5.9^0$C-$11.9^0$C have been observed for the outlet flow velocity ranging from 1.8m/s to 4.1 m/s. At higher outlet velocity and maximum temperature difference, the system is most efficient to be used.

# NOMENCLATURE

| | |
|---|---|
| m | mass flow rate of air through the pipe |
| $C_p$ | specific heat capacity |
| $C_d$ | coefficient of discharge of the pipe |
| d | diameter of the pipe |
| v | velocity of the air |
| $Q_c$ | Total cooling |
| $T_{inlet}$ | Temperature at the inlet |
| $T_{outlet}$ | Temperature at the outlet |
| PVC | polyvinyl chloride |
| COP | coefficient of performance |
| EER | energy efficiency ratio |
| GHE | ground heat exchanger |
| GCHP | ground coupled heat pump |
| EAHE | earth air heat exchanger |

# CHAPTER 1

# INTRODUCTION

## 1.1 BACKGROUND

Saving energy is one of the most important global challenges. A large portion of the global energy supply is used for electricity generation and space heating, having the major portion derived from fossil fuels. Fossil fuels are non renewable resources and their combustion is harmful to the environment, through the production of greenhouse gases, which effects the climate change and other pollutants. Fossil fuel depletion along with pollutant emissions and global warming are important factors for sustainable and environmentally benign energy systems. These concerns have motivated efforts to reduce society's dependence on non renewable resources, by reducing demand and substituting alternative energy sources. First of all efforts are focused on producing electricity with higher efficiency. Old power plants are more rapidly phased out and replaced by new, more efficient plants. More efficient use of energy not only reduces the consumption of electricity, but also lowers the consumption of non renewable resources. Renewable energy resources are sought that are more environmentally benign and economic than conventional fossil fuels.

Beyond fossil fuels, the earth's crust stores an abundant amount of thermal energy [1]. Geothermal systems are relatively benign environmentally, with the emissions much lower than for conventional fossil fueled systems. Geothermal energy is the heat from within the earth. Geothermal energy is generated in the earth's core and core is made up of very hot magma (melted rock) surrounding a solid iron center. High temperatures are continuously produced inside the earth by the slow decay of radioactive materials and this process is natural in all rocks. The outer core is surrounded by the mantle, which is made of magma and rock. The outer layer of the earth, the land that forms the continents and ocean floors is called the crust. The crust is not a solid piece, like the shell of an egg, but it is broken into pieces called plates. Magma comes close to the earth surface near the edges of these plates. We can dig wells and pump the hot underground water to the surface. People use geothermal energy to heat their homes and to produce electricity.

In many cases solar energy is directly or indirectly used to supply heat or electrical energy. Solar gains inside the building are avoided to reduce cooling needs or the size of the air-conditioning unit. Using the earth as a component of the energy system can be accomplished through three primary methods i.e direct, indirect and isolated. In direct system, the building envelope is in contact with the earth, and the conduction through the building elements (primarily walls and floor) regulates the interior temperature. In indirect system, the building interior is conditioned by air brought through the earth, such as in earth-to-air heat exchangers [2]. The isolated system uses earth temperatures to increase the efficiency of a heat pump by moderating temperatures at the condensing coil. The geothermal heat pump is the example of an isolated system. This thesis will focus on indirect systems.

Indirect systems, i.e earth-to-air heat exchangers, sometimes called ground tubes, or ground coupled air heat exchangers are an interesting and promising technology. Tubes are placed in the ground, through which air is drawn. Because of the high thermal inertia of the soil, the air temperature variations at the ground surface exposed to the exterior climate are damped deeper in the ground. Further a time lag occurs between the temperature variations in the ground and at the surface. At a sufficient depth the ground temperature is higher than the outside air temperature in winter and lower in summer. When fresh air is drawn through the earth-to-air heat exchangers the air is thus cooled in summer and heated in winter. In combination with other  systems and good thermal design of the building, the earth to air heat exchanger can be used to preheat air in winter and avoid air-conditioning units in buildings in summer, which results in a reduction in electricity consumption of a building.

## 1.2 GROUND COUPLED HEAT EXCHANGER:

A ground coupled heat exchanger is an underground heat exchanger that can capture heat from and dissipate heat to the ground. They use the earth's near constant subterranean temperature to warm or cool air or other fluids for residential, agricultural or industrial uses. They are also called earth tubes or earth-air heat exchangers or ground tube heat exchanger. Earth tubes are often a viable and economical alternative or supplement to conventional central heating or air conditioning systems since there are no compressors, chemicals or burners and only blowers are required to move the air. These are used for either partial or full cooling and their use can help building meet passive house standards.

In the case of cooling a building, the ground is the heat sink, and the building to be cooled acts as heat source. In the case of heating, these functions are reversed- the ground becomes the heat source and the building heat sink. Heat is extracted from or rejected to the ground by means of buried pipe, through which a fluid flows. The buried pipe is commonly called ground loop heat exchanger.

They can make significant contributions to reductions in electrical energy usage but in this system, the actual heat transfer to and from the ground loop heat exchanger varies continuously due to changing building energy requirements. Despite the changing environmental conditions, the net fall in temperature that can be adjusted with the flow of the air so as to give comfort conditions in the room. The resulting variations impact the coefficient of performance (COP) of the system and thus influence the overall system performance in a significant way.

## 1.3 When should earth tubes be used?

- Best in climates in extreme heat and cold. The high difference between the ambient temperatures and the required indoor temperatures create the best opportunity for earth tubes to produce valuable results.
- Need available land to accommodate the length of tubes.
- Great opportunity to place them under the building floor when constructing a new building.

## 1.4 Ground heat transfer mechanism

The temperature field in the ground is influenced by different quantities (see Fig. 1.1). Absorption of the solar radiation depends on the ground cover and color, while the long wave radiant loss depends on soil surface temperature [3].

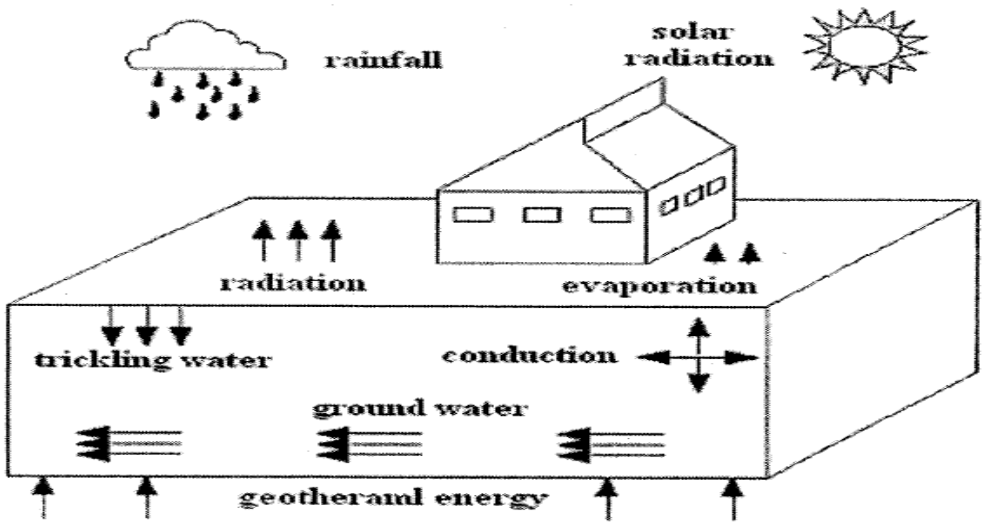


Fig 1.1: Different environmental influences and heat transfer mechanisms that influence the temperature field in the ground [3]

The net radiant balance between solar gain and long wave loss is usually positive in summer and negative in winter. This causes heat to flow down from the surface into the ground in the summer and upward to the surface during the winter. The net radiant balance also determines the relationships between the averages of the earth surface and the ambient air temperatures. By shading the soil in summer while partially exposing it to the sky in winter, for example, with trees, it is possible to lower the ground temperature in summer to a greater extent while possibly increase the ground temperature in winter somehow.

The performance of ground coupled air heat exchanger is directly related to the thermal properties of the ground. The ground has thermal properties that give it a high thermal inertia. The heat transfer mechanisms in soils are, in order of importance: conduction, convection and radiation. The temperature field in the ground depends on the soil type and the moisture contained respectively.

## 1.5 Types of Ground Coupled Heat Exchangers

There are two general types of ground heat exchangers: open and closed. In an open system, the ground may be used directly to heat or cool a medium that may itself be used for space heating or cooling. Also, the ground may be used indirectly with the aid of a heat carrier medium that is circulated in a closed system.

### 1.5.1 Open systems

In open systems, ambient air passes through tubes buried in the ground for preheating or pre-cooling and fresh fluid is circulated through the ground loop heat exchanger. This system provides ventilation while hopefully cooling or heating the building’s interior.

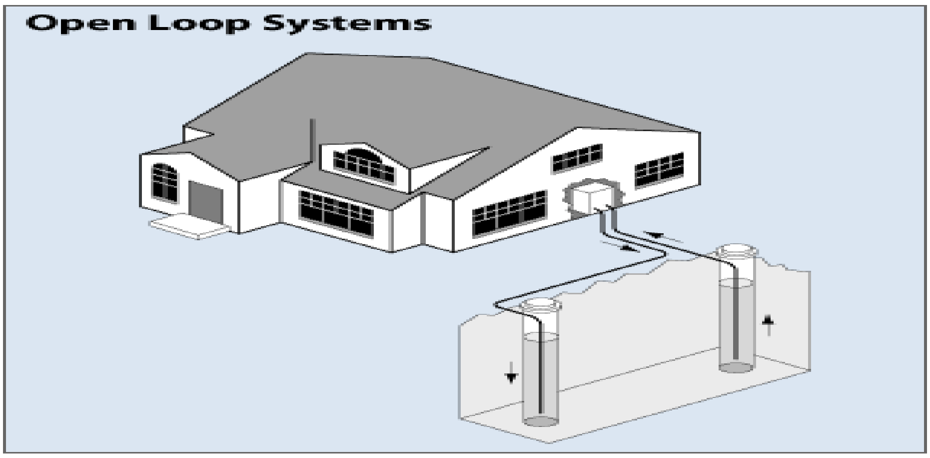


Fig1.2: Basic principle of ground preheating or pre-cooling of air in an open system [4]

### 1.5.2 Closed Systems

In closed systems, both the ends of the pipe are kept inside the control environment, which can be a room in case of air and a tank in case of water, the system is said to be closed loop because the same fluid is passed continuously over and over through the loop.

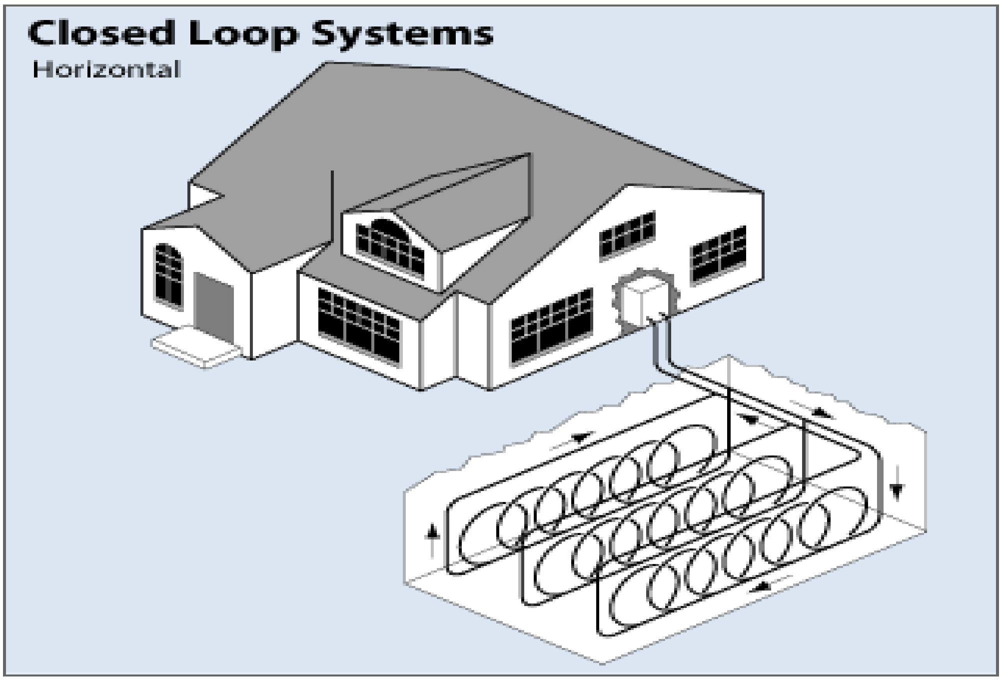


Fig 1.3 Closed Loop System[4]

Closed type ground heat exchangers can be either in horizontal, vertical or oblique position and a heat carrier medium is circulated within the heat exchanger. Fig1.3 indicates the horizontal type which has a number of pipes connected either in series or in parallel. This configuration is usually the most cost-effective when adequate yard space is available and trenches are easy to dig. The trenchers have a depth of 1–2m in the ground and usually a series of parallel plastic pipes is used. Fluid runs through the pipes in a closed system [5]. Horizontal ground loops are the easiest to install while a building is under construction. However, new types of digging equipment allow horizontal boring and thus it is possible to retrofit such systems into existing houses with minimal disturbance of the top soil and even allow loops to be installed under existing buildings or driveways. To save surface area with ground heat collectors, some special ground heat exchangers are used. Exploiting a smaller area at the same volume, trench collectors are best suited as shown in fig1.4. The main thermal recharge for all horizontal systems is provided mainly by the solar radiation to the earth's surface. It is important not to cover the surface of horizontal type heat exchanger.

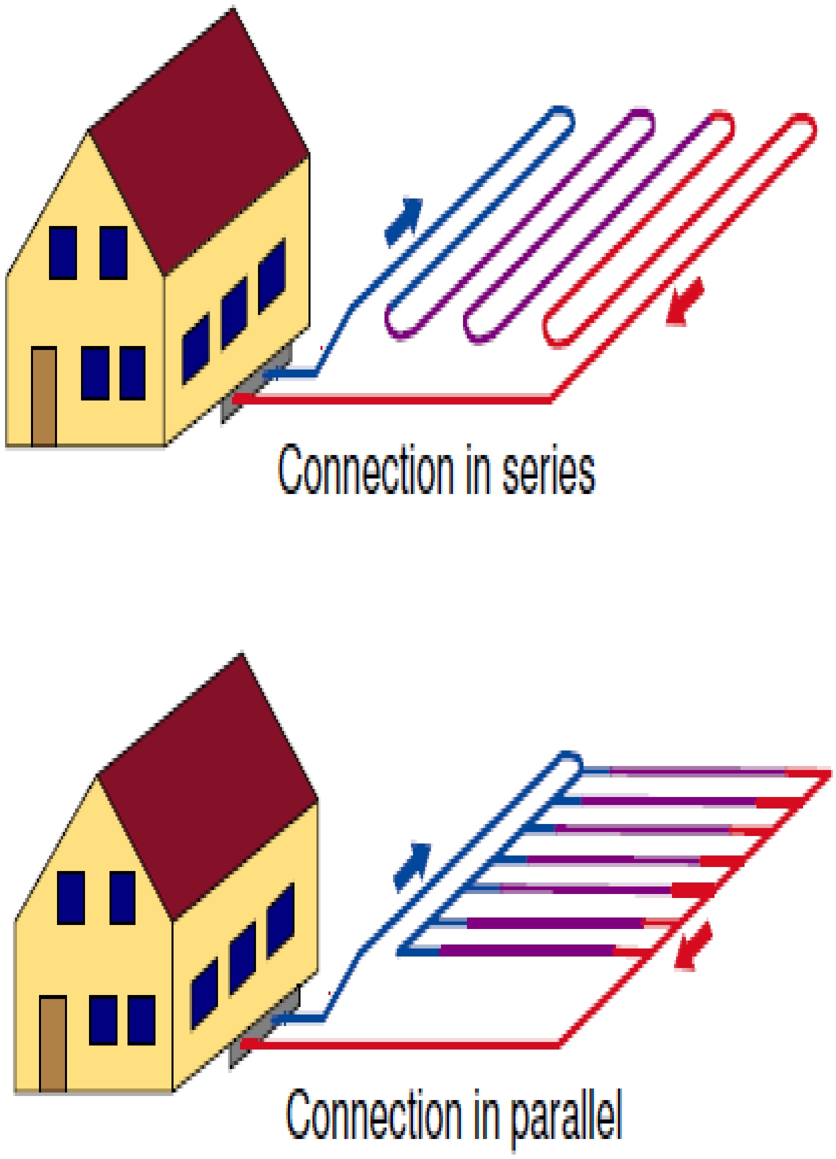


Fig 1.4: Horizontal type ground heat exchanger [4]

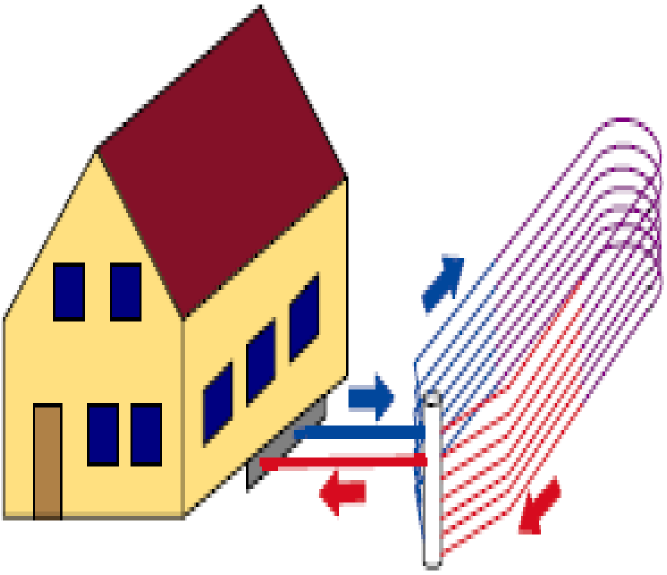

Fig 1.5: Trench Collector [4]

Vertical ground heat exchangers or borehole heat exchangers, shown in Fig 1.6, are widely used when there is a need to install sufficient heat exchange capacity under a confined surface area.

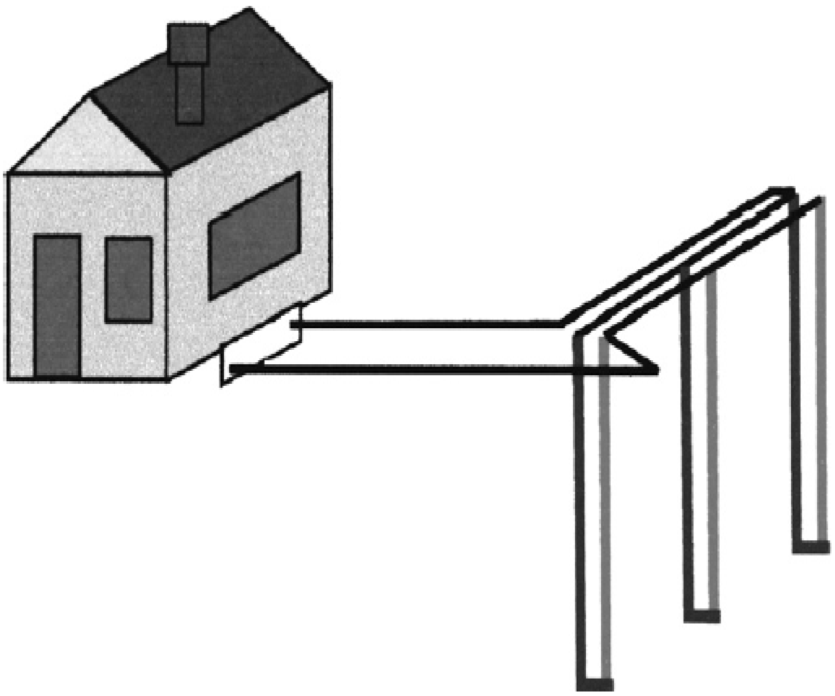

Fig 1.6: Vertical ground heat exchangers [5]

In a standard borehole heat exchanger, plastic pipes (polyethylene or polypropylene) are installed in boreholes, and the remaining space in the hole is grouted [6]. Vertical loops are generally more expensive to install, but require less piping than horizontal loops because the earth deeper down is cooler in summer and warmer in winter, compared to ambient temperature.

Vertical type borehole heat exchangers can be classified into two basic types:

(a) A pair of straight pipes having U-turn at the bottom side.

(b) Coaxial or concentric pipe configuration in which one pipe is placed inside the pipe with bigger diameter.

## 1.6 Advantages and Disadvantages of Ground Heat Exchanger

### 1.6.1 Advantages:

1. The ground heat exchangers are very simple to use and easy to maintain.
2. In the long run, the low maintenance cost and the electricity cost saving make up for the initial investment.
3. Ground heat exchangers uses only the energy stored in the earth and have no harmful impact on the environment.

### 1.6.2 Disadvantages:

1. High initial investment cost.
2. Use of ground heat exchangers is recommended in new houses which has excellent insulation and air-tightness.
3. Space requirement is the major hindrance to the adoption of ground heat exchangers.
4. The design and installation of an effective ground heat exchange depends on the local geology and the heating or cooling requirements of the building and to get the benefit of a well designed system, one needs to consult a expert installer which increases the cost of the system

# CHAPTER 2

# LITERATURE REVIEW

Literature review has been carried out to study the development in the field of ground heat exchangers. The literature consists of research papers mainly from the ground heat exchanger. The main points of my literature review are:

**Zoi Sagia et al [7]** studied the borehole resistance and heat conduction around vertical ground heat exchangers. Several parameters such as geometrical attributes of heat exchanger in the borehole pipes characteristics and grout's thermal conductivity affects the borehole thermal resistance in the ground heat exchanger installations.

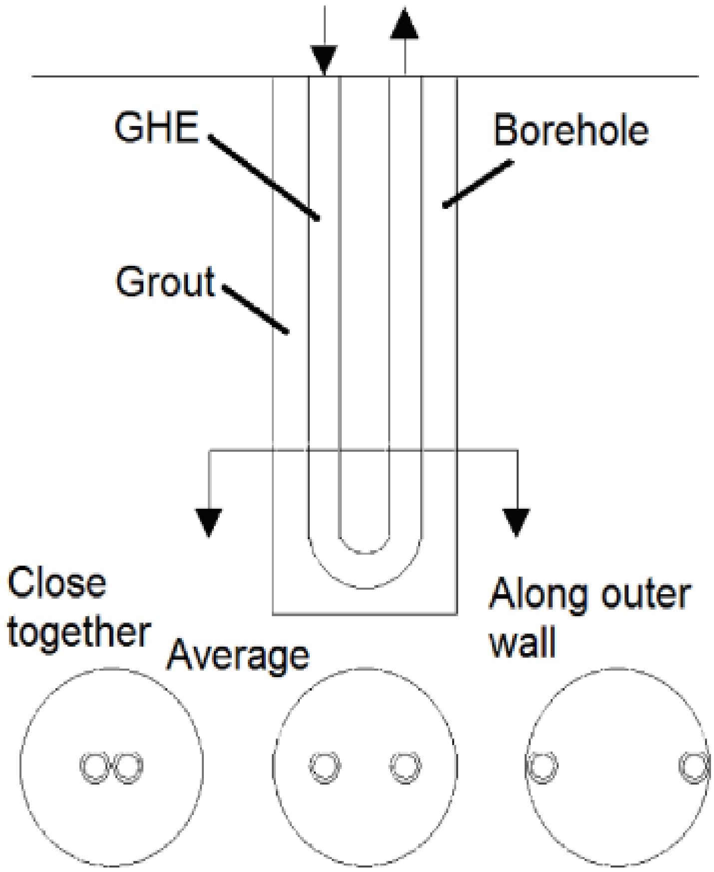


Fig 2.1: Vertical Ground Heat Exchanger and Configurations

Thermal conductivity of concrete (50% Quartz sand) was 1.9W/mK and was highest among the different grout mixtures. The borehole thermal resistance decreased as shank spacing (center-to-center distance) between ground heat exchanger pipes was increased.

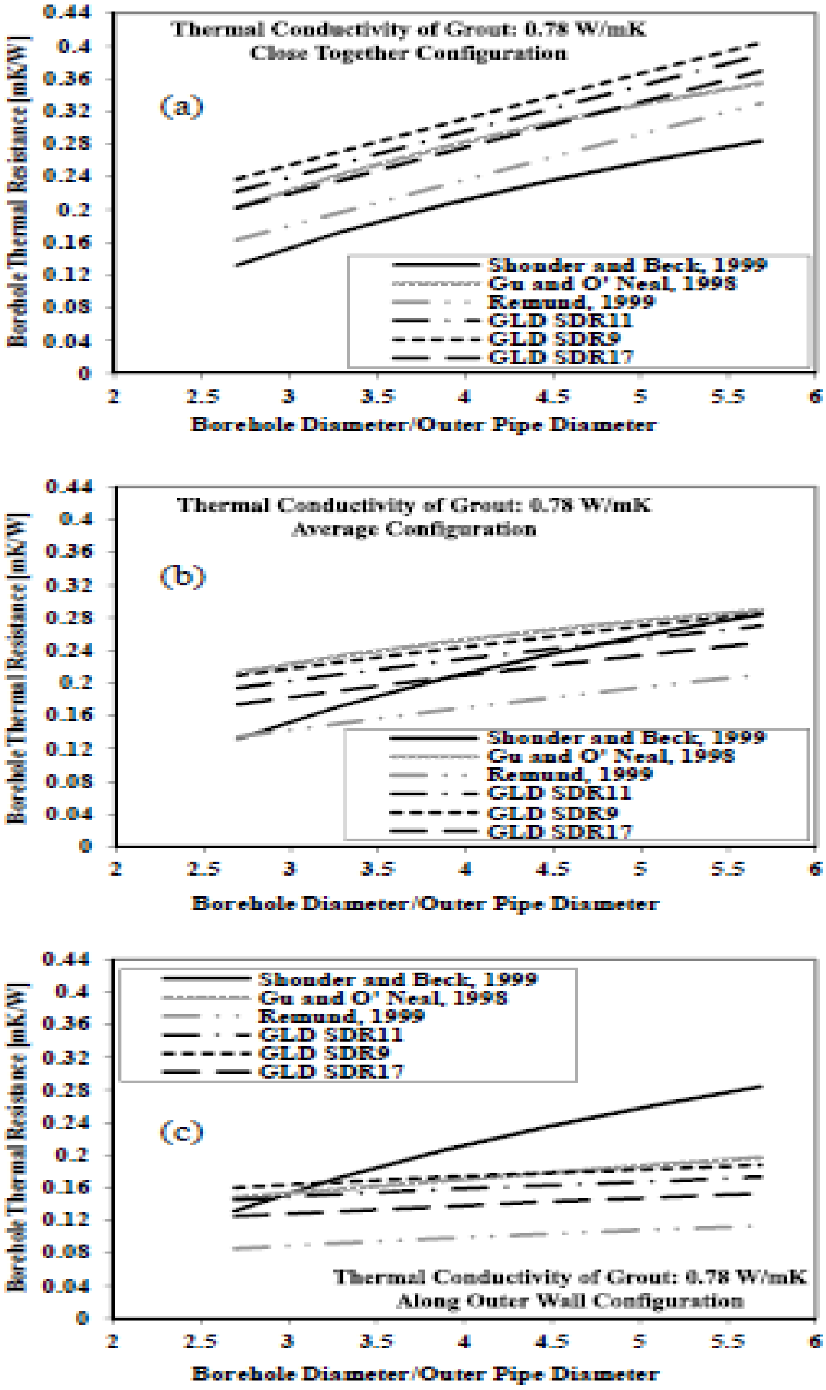


Fig2.2: Borehole thermal resistance versus dimensionless ratio of Borehole diameter to Outer Pipe diameter for (a) close together, (b) average and (c) along outer wall configuration

Standard dimension ratio (SDR) is the ratio of the pipe outer diameter to its wall thickness and it is a common method of rating plastic pipes and pipe materials of at least 6 bar should be used [8]. Ground loop design (GLD) software was used for comparing different analytical correlations for borehole thermal resistance calculation.

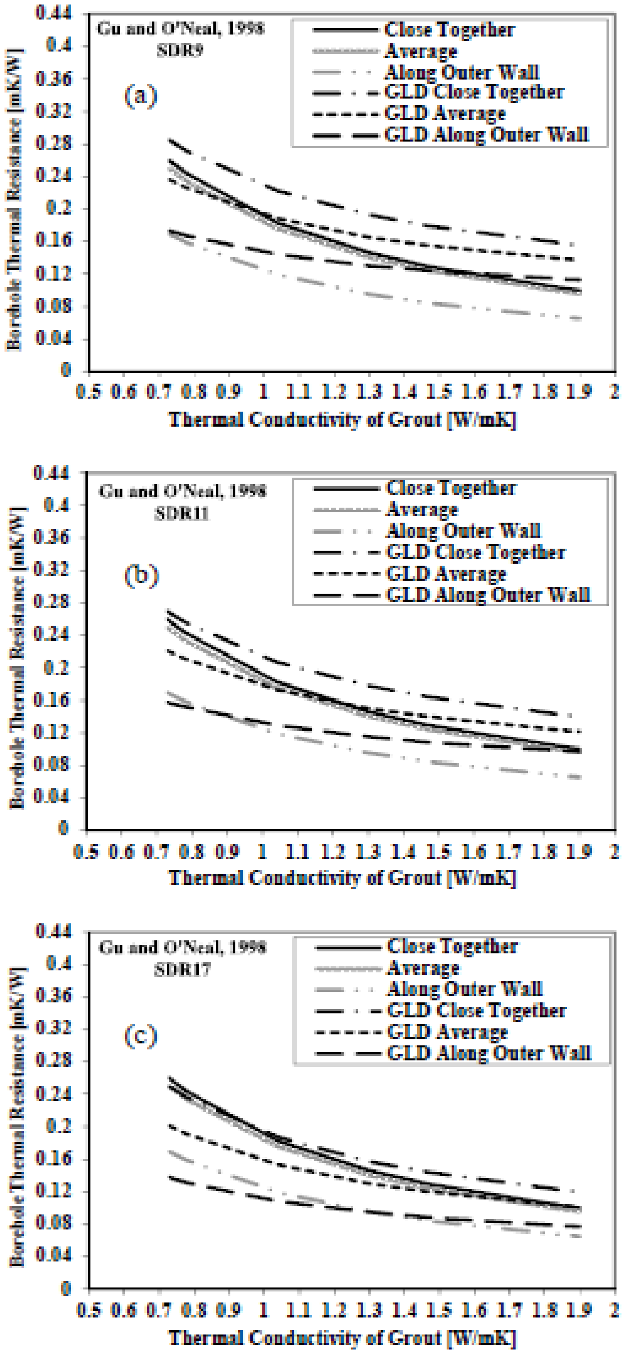


Fig 2.3: Borehole thermal resistance versus thermal conductivity of grout for (a) SDR 9, (b) SDR11, (c) SDR 17.

A rise in grout's thermal conductivity leads to a fall of borehole resistance. The slighter wall pipe enables a bigger heat transfer rate between the heat carrier fluid and the ground.

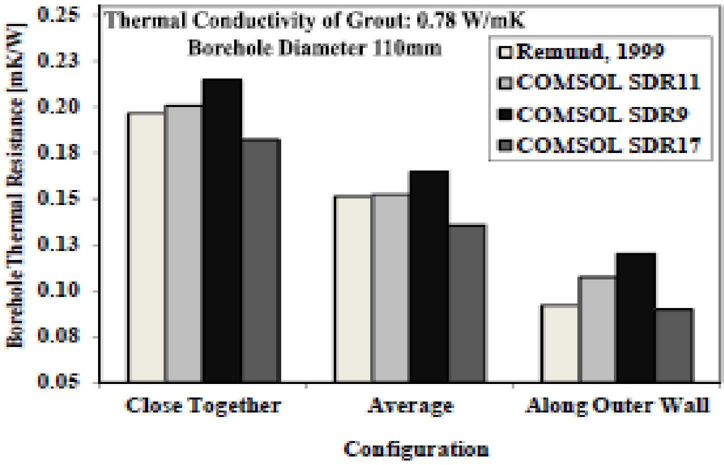


Fig 2.4: Borehole thermal resistance for a grout of 0.78 W/m K thermal conductivity for three configurations..

**Fabrizio Ascione et al [9]:** The experiment was conducted at three different cities of Italy and the performance evaluation was done for ground heat exchanger in both summer and winter conditions. The following conclusions were made out:

- The ground heat exchanger placed in the wet/humid soil gave the more encouraging results than the other two ground heat exchangers.
- Different materials like PVC, metal and concrete were used as tube materials showed no effect on the performance of the ground heat exchanger.
- Ground heat exchangers were tested at different air speeds but low speed of 8 m/s was preferred as it decreases the pressure drop inside the tubes and fan energy requirements.

**Vikas Bansal et al [10]** investigated the performance of horizontal earth pipe air heat exchanger for winter heating and effect of flow velocity and material of the pipe. A transient and implicit model was developed to predict the performance of the earth air heat exchanger. The 23.42 m long earth tube was used and gave the heating in the range of 4.1-4.8$^0$C for flow velocities of 2-5 m/s. In this study it was concluded that the performance of the earth pipe air heat exchanger system did not got affected by the material of the buried pipe, so therefore a cheaper material can be used for making the pipe.

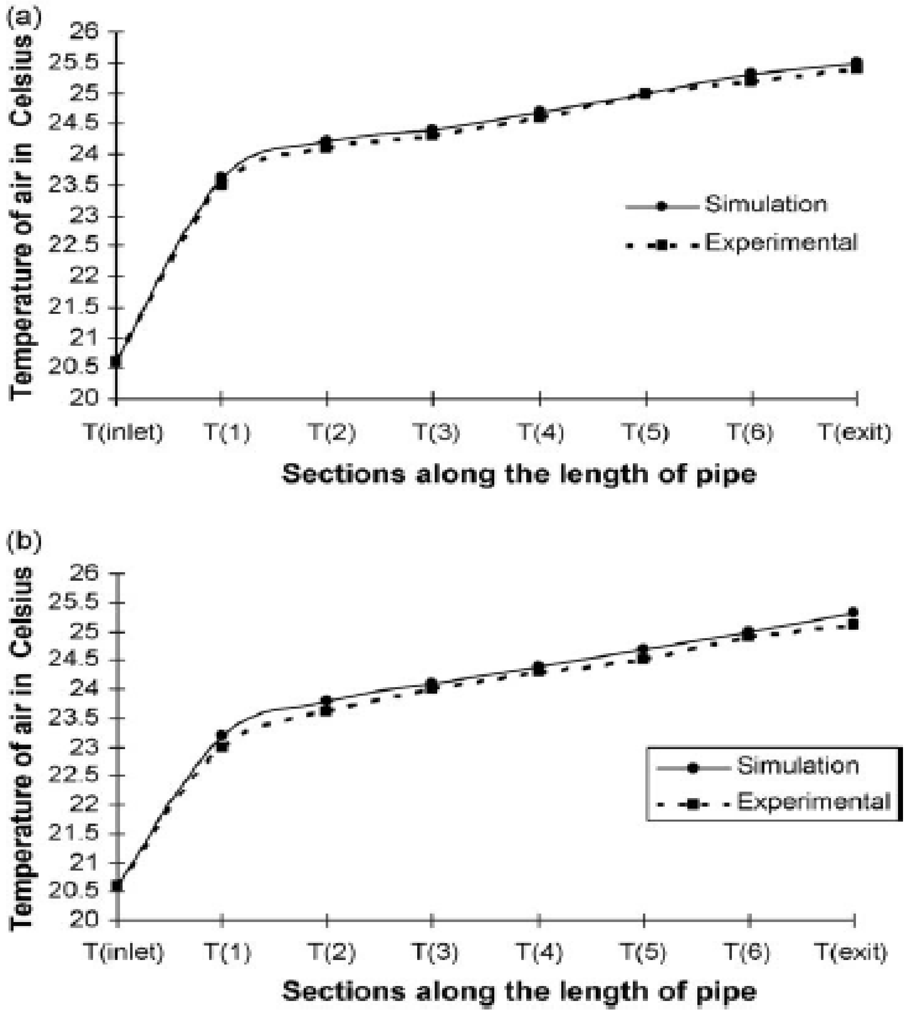


Fig 2.5: Temperature distribution along the length of the pipe for exit velocity 2.0 m/s for (a) steel pipe (b) PVC pipe.

**W.H.Leong et al [11]** studied the effect of soil type and moisture content on ground heat pump performance and found that the performance of a ground heat pump system depended strongly on the moisture content and the soil type (mineralogical composition). Alteration of soil moisture content from 12.5% of saturation to complete dryness decreased the ground heat pump performance, and any reduction of soil moisture within this range has a devastating effect.

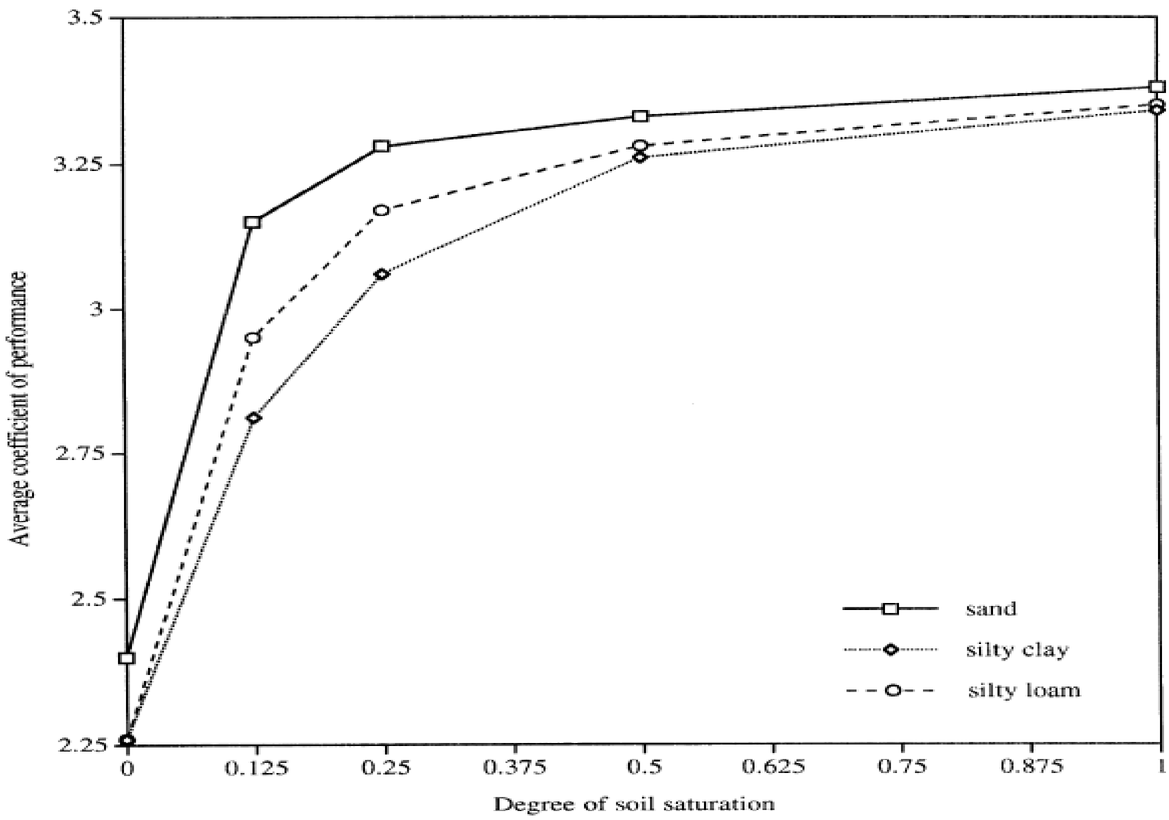


Fig.2.6: Variation of the average COP vs soil degree of saturation.

**Weibo Yang et al [12]** studied a two region simulation model of vertical U-tube ground heat exchanger and its experimental verification and divided the heat transfer region of GHE into two parts at the boundary of borehole wall, and the two regions are coupled by the temperature of borehole wall. He concluded that the outlet fluid temperature of GHE, borehole wall temperature and COP of heat pump all dropped deeply during the startup time, and then the drop extent gradually became tardiness when the operation time exceeds about 200 h and the performance of the GCHP system was very unstable during the starting stage and was strongly affected by the ground initial temperature. But it reached quasi-steady state when the operation time exceeded the starting stage and then got affected mainly by the variation of building load.

**Rakesh Kumar et al [13]** designed and optimized earth-to-air heat exchanger using a genetic algorithm and found the impact of four inputs humidity, ambient temperature, ground surface temperature and ground temperature at burial depth on outlet temperature of earth-air heat exchanger was studied through sensitivity analysis. Outlet temperature was significantly affected by ambient air temperature and ground temperature at burial depth.

**Kyoungbin Lim et al [14]** performed the experiment to measure the thermal performance of ground heat exchanger. Thermal response test using a vertical borehole heat exchanger at two different locations was done. The property of the rock at two regions was same but the value of thermal conductivity and thermal resistance was different, the reason for this was due to the groundwater flow, difference of borehole length and the weather variation during the measured period. Study also concluded that ground temperature remains stable over the borehole depth of 3m.

**Arvind Chel et al [15]** investigated the performance evaluation and life cost analysis of earth to air heat exchanger integrated with adobe building for New Delhi composite climate. The following conclusions were made from the experiment:

- The adobe house has considerable energy saving potential for Indian climatic conditions. These adobe houses can be easily adopted for all locations, especially in hot and dry climatic regions of semi-urban and rural areas all over the world for achieving the thermal comfort.

- The total annual energy saving potential of adobe house for three conditions: (i) before renovation, (ii) after renovation and (iii) with EAHE for six rooms for renovated adobe house was calculated as 4182kWh/year, 4946kWh/year and 10321kWh/year respectively. This results in mitigation of CO2 emissions nearly equal to 7 tons/year, 8 tons/year and 16 tons/year respectively. Hence, annual carbon credits that can be earned by the adobe house for three conditions are €140/year, €160/year and €320/year respectively.

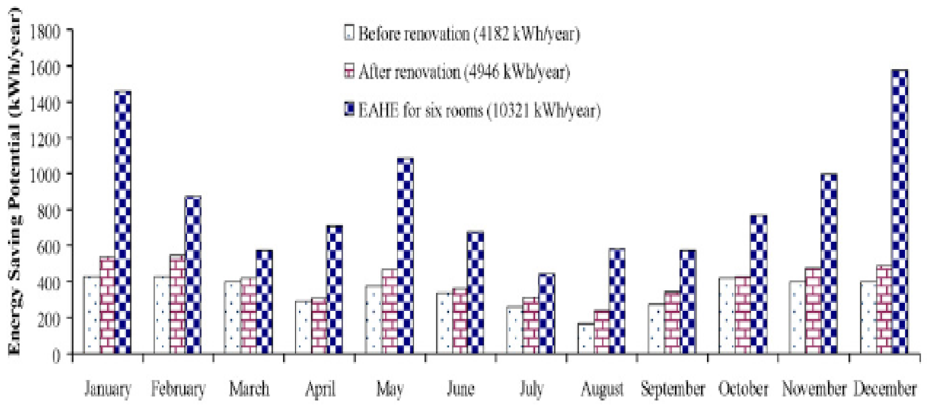


Fig. 2.7: Comparison of annual energy saving potential (i)before renovation (ii) after renovation (iii) with EAHE for six rooms after renovation.

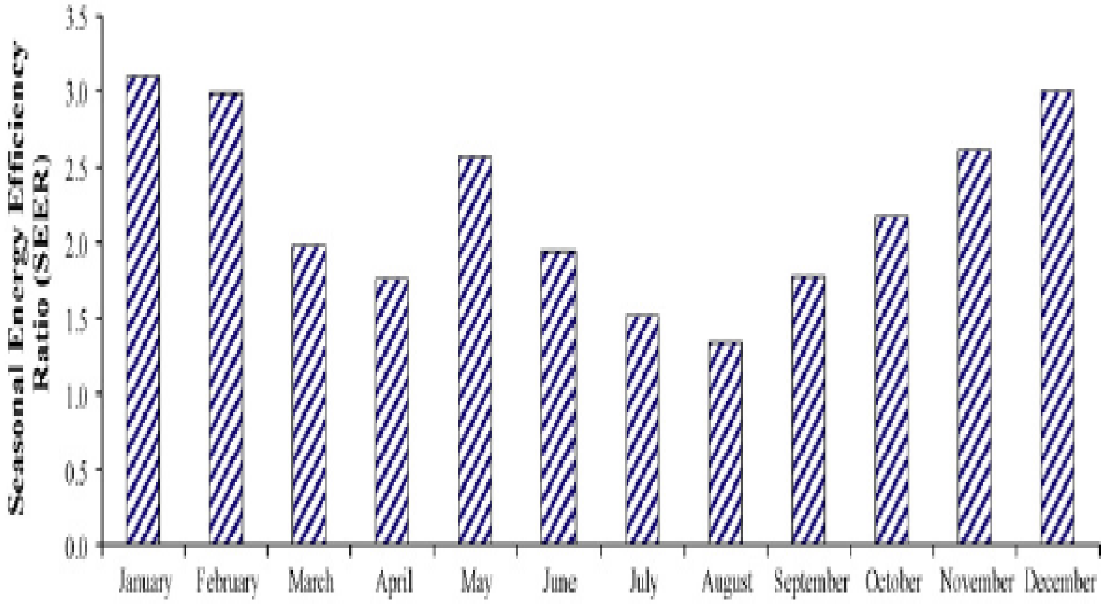


Fig 2.8: Seasonal energy efficiency ratio (SEER) of EAHE for heating/cooling.

**Jyotirmay Mathur et al [16]** studied the performance of the earth-air-tunnel heat exchanger by integrating with evaporative cooler at the outlet.

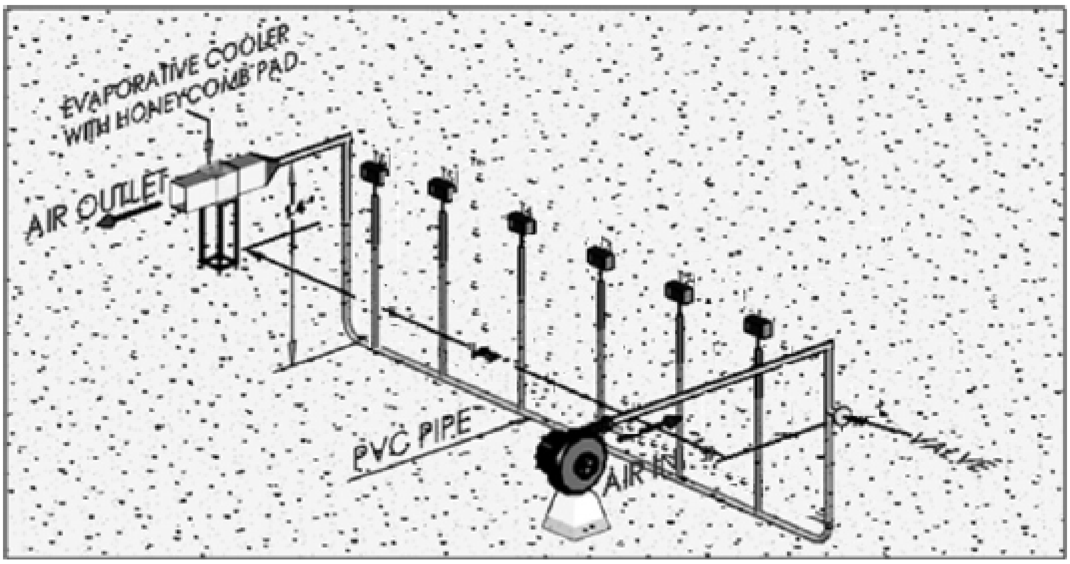


Fig 2.9: Experimental set-up of integrated EATHE- evaporative cooling system

Year round hourly analysis was done at the integrated system in Ajmer (Rajasthan) and found that integrated system performed better than simple earth air tunnel heat exchanger but during pre-monsoon and monsoon period i.e from June to September, it was not able to treat sufficiently the ambient air to make it thermally comfortable.

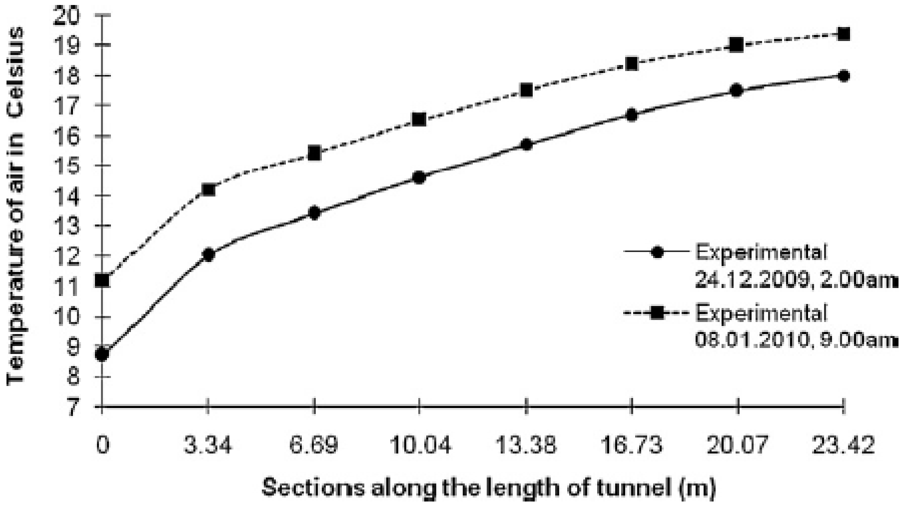


Fig 2.10: Temperature variation along the length of tunnel in winter conditions for air velocity of 5m/s.

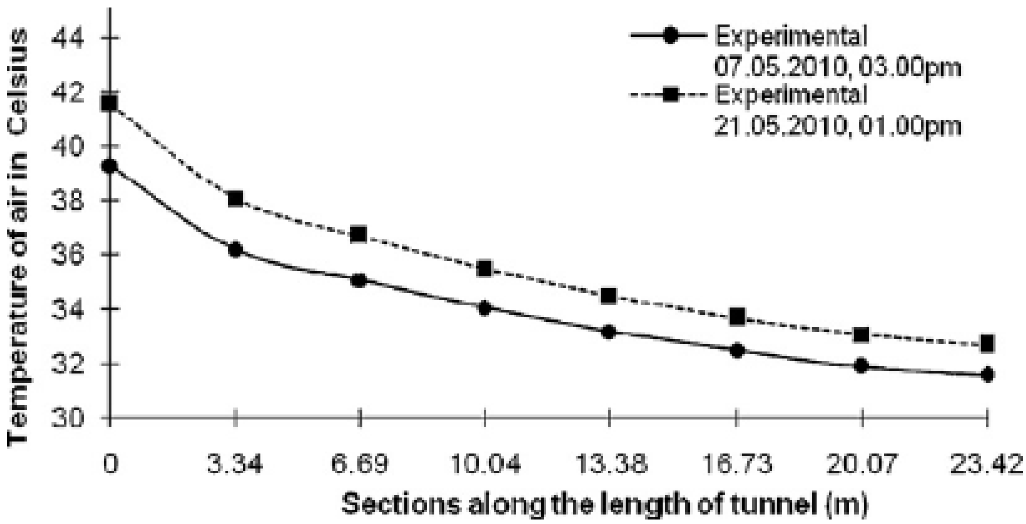


Fig 2.11: Temperature variation along the length of tunnel in summer conditions for air velocity of 5m/s.

**G.Colangelo et al [17]** investigated the performance of horizontal ground heat exchanger for different configurations. Three different configurations namely linear, helical and slinky has been studied at different depths and effect of velocity has been studied. The CFD simulations have been carried out for depth up to 2.5 m for summer and winter conditions.

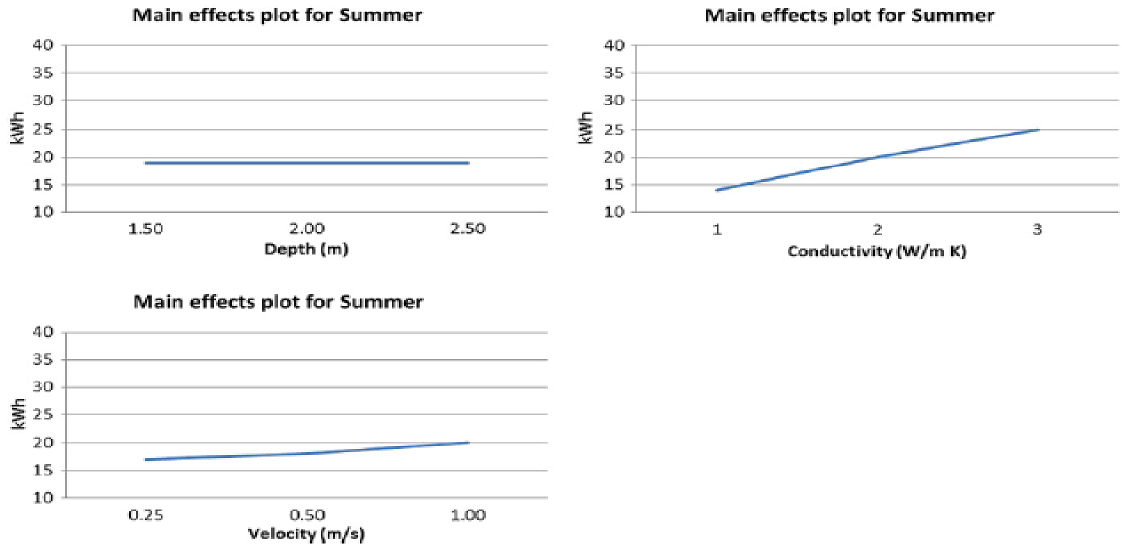


Fig 2.12: Mean thermal energy (kwh) transferred to the ground for linear ground heat exchangers in summer

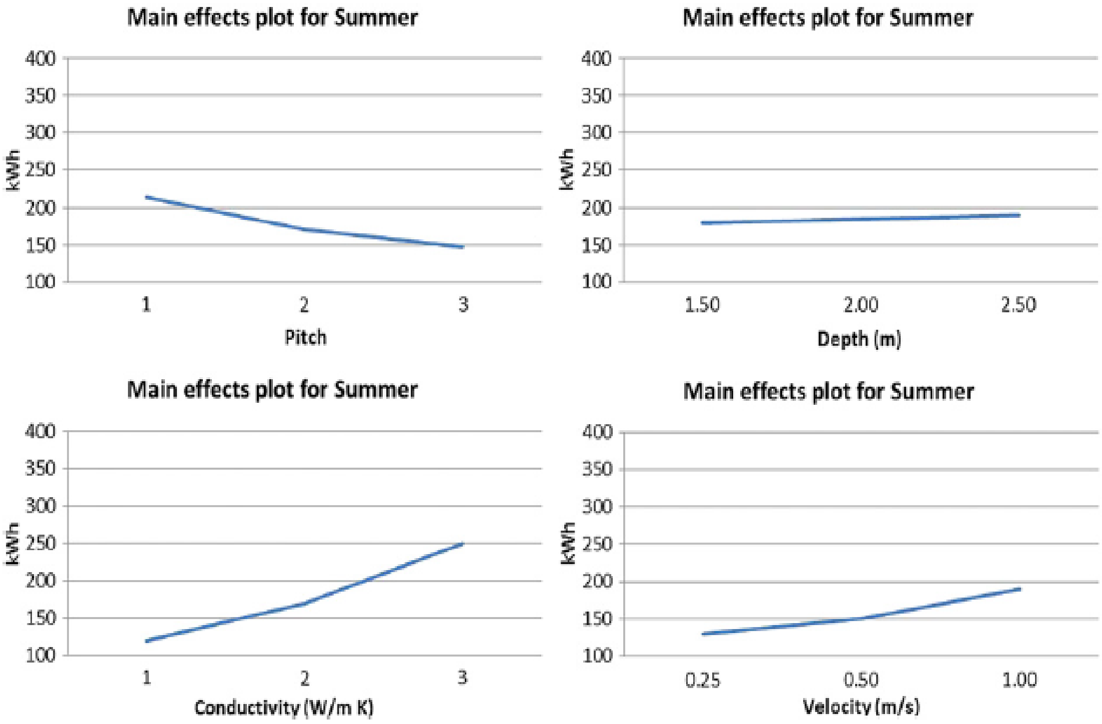


Fig 2.13: Mean thermal energy (kwh) transferred to the ground for helical ground heat exchangers in summer

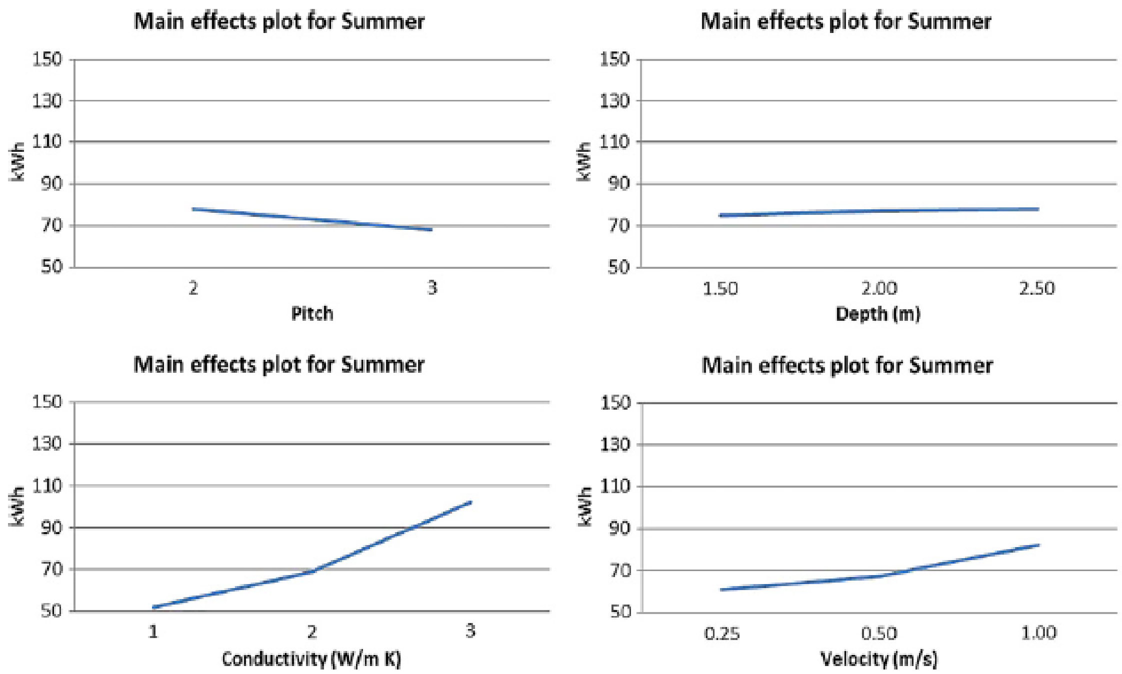


Fig 2.14: Mean thermal energy (kwh) transferred to the ground for slinky ground heat exchangers in summer

After studying the simulated results for different configurations, it leads to assert that the depth of the ground does not play important role up to 2.5 m. Among linear, helical and slinky configuration, helical heat exchanger showed the best results but it has to be paid with high installation costs.

**Akio Miyara et al [18]** performed the experiment to study the different configurations of vertical ground heat exchangers with a steel pile foundation. The double tube, U tube and multi tube ground heat exchangers were used for the experiment to investigate the heat exchange rates at different flow rates. The performance of the ground heat exchangers was evaluated at different flow rates of 2, 4, 8 l/min.

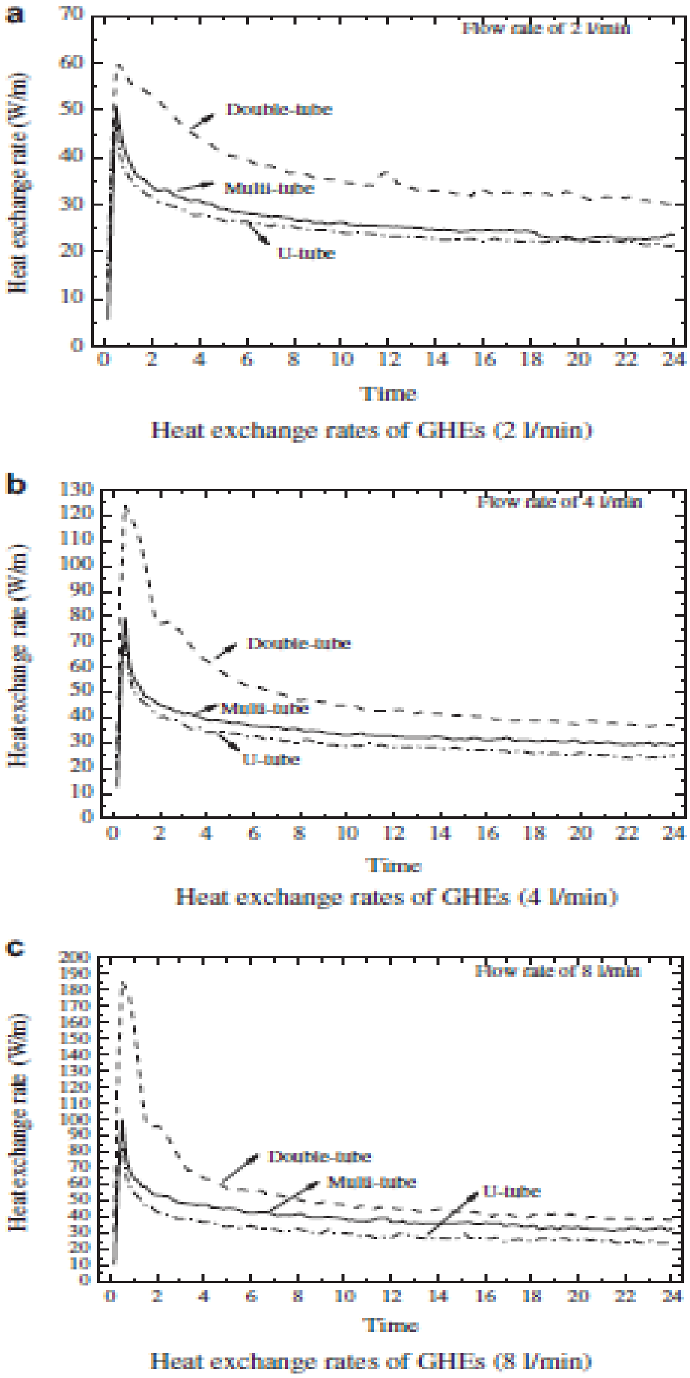


Fig 2.15: Heat exchange rates of GHEs of each flow rate. (a) Heat exchange rates of GHEs (2l/min) (b) Heat exchange rates of GHEs (4l/min) (c) Heat exchange rates of GHEs (8l/min)

The results shows that the double tube ground heat exchanger has the highest heat exchange rate, followed by the multi tube and U-tube and the heat exchange rates of the double tube and multi tube ground heat exchangers increases in the high flow rate region but U-tube remains constant.

# CHAPTER 3
# DESIGN PARAMETERS

## 3.1 Tube depth

The ground temperature is defined by the external climate and by the soil composition, its thermal properties and water content. The ground temperature fluctuates in time, but the amplitude of the fluctuation diminishes with increasing depth of the tubes, and deeper in the ground the temperature converges to a practically constant value throughout the year. On the basis of temperature distribution, ground has been distinguished into three zones [19]:

- Surface zone: This zone is extended up to 1m in which ground is very sensitive to external temperature.
- Shallow zone: This zone is extended up to 1-8 m depth and temperature is almost constant and remain close to the average annual air temperature.
- Deep zone: This zone is extended up to 20 m and ground temperature is practically constant.

Soil temperature at a depth of about 10 feet or more stays fairly constant through out the year and stays equal to the average annual temperature [20]. After a depth of 3-4 m in the ground, temperature remains nearly constant [5].

## 3.2 Tube length, tube diameter and air flow rate

The total surface area of the ground coupled air heat exchangers is a very important factor in a overall cooling capacity, which can be increased by two ways, either increasing the tube length or tube diameter [8]. Optimum tube diameter varies widely with tube length, tube costs, flow velocity and mass flow rate. A diameter should be selected that it can balance the thermal and economic factors for the best performance at the lowest cost. The optimum is determined by the actual cost of the tube and the excavation. Excavation costs in particular vary greatly from one location and soil type to another. The optimum tube length was determined by passing the air from the blower at different lengths. The air was passed through the inlet at the minimum speed of the blower i.e 7 m/s and at the length of 13.6 m, the outlet velocity was 1.8 m/s, any further increase in length used to reduce the velocity at outlet which was not required. The 15 cm diameter pipe was considered for the experiment and 6 kg bar pressure pipe was used.

## 3.3 Tube material

Various factors need to be considered while deciding upon the material of the pipe for this system. There can be many options while selecting the material of the pipe to be used with the system. As the pipe has to be buried underground, it is not easy to replace the pipe often. Hence the longevity of the pipe is of utmost importance while taking care of the heat transfer characteristics of the system. There was a wide range of materials available for the selection for use in our system.

- **Copper**

Copper is usually the best choice for designing materials for heat transfer. The various advantages of using copper for such systems are mainly because of its high thermal conductivity. It is also resistant to corrosion by liquids.

But one key disadvantage of using copper for our system was its high price. Moreover, it is generally not suitable for applications where high forces are applied on these pipes as these pipes are prone to bending.

- **Aluminium**

Aluminium is known for its high thermal conductivity and thus was actively considered for use in our system. It is found freely in the earth's crust but never found free. It is a good conductor of heat and electricity. But as in case of copper, the cost of aluminium is very high and makes it unsuitable for our system where we are concerning ourselves with cost effectiveness of the overall set-up.

- **Concrete**

Concrete-mix pipes are obtained by mixing cement with concrete in adequate proportions and using reinforcements of steel wire or steel bars. These pipes are of high strength and are resistant to corrosion from various environmental factors.

But they have an inherent property of porosity that will induce losses for our system. Because of porosity, although they will be better able to transfer heat but a lot of fluid will be lost to diffusion through the walls of the concrete pipe. Thus, these pipes might not prove to be efficient.

- **Poly-vinyl Chloride(PVC)**

Poly-vinyl chloride or PVC pipes have started being used widely in home applications and transfer of highly reactive chemical substances in various industrial plants. Their non-reactivity with a wide range of chemicals and environmental agents has made them increasingly popular with a wide range of applications. Their other advantages include the ease of handling because of their light weight. Moreover they have good ageing properties.

But at temperatures higher than $80^0$C these pipes tend to become soft. They have high coefficient of thermal expansion. But since we will require our system to cool environment air only, we will not encounter such high temperatures. The main factor for considering PVC pipe was its durability and cost.

# CHAPTER 4
# CFD MODEL

Computational fluid dynamics (CFD) is well known as a powerful method to study heat and mass transfer problems. CFD codes are structured around the numerical algorithms that can tackle fluid flow problems. To examine the complicated airflow and heat transfer in earth tubes, Ansys software 14.0 was used. Fluent which is the integral part of Ansys includes the sophisticated user interfaces to input problem parameters and to examine the results. CFD codes in FLUENT contain three main elements:

- Pre-processor consists of the input of a flow problem to a CFD program by means of definition of the geometry and division of the domain into a smaller, non-overlapping sub-domains to create the mesh.
- Solver uses the finite control volume method for solving the governing equations of fluid flow and heat transfer.
- Post-processor shows the results of the simulations using contour plots, graphs, animations etc.

The main objective of the CFD study was to investigate the performance of the underground duct and CFD simulations were performed using Fluent module considering k-ε model.

4.1 Model Description:

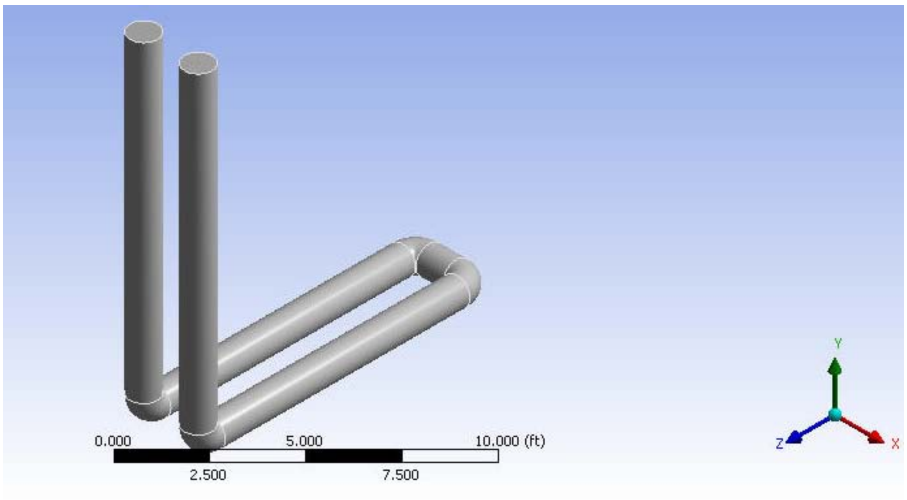


Fig 4.1: Earth tube model

4.2 Meshing:

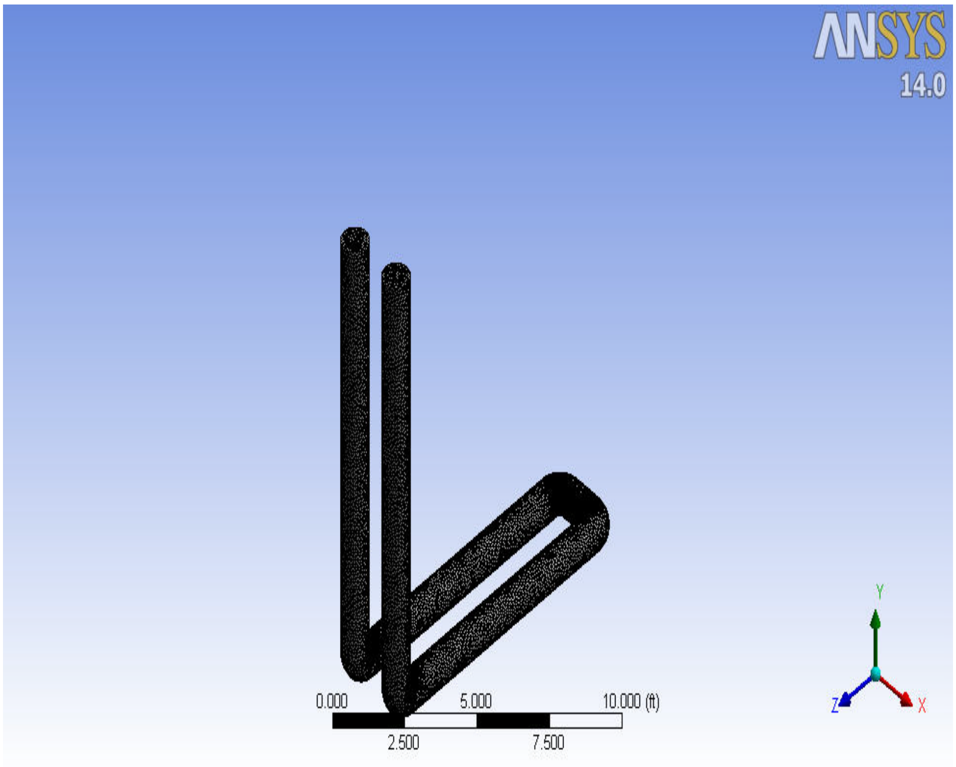


Fig 4.2: Tetrahedral Meshing

After meshing, 153298 nodes and 132637 elements were created.

Parameters used in simulation:

| Material | Density ($kg/m^3$) | Specific heat capacity (J/kg K) | Thermal Conductivity (W/mK) |
|---|---|---|---|
| Air | 1.225 | 1006 | 0.0242 |
| PVC | 1380 | 900 | 0.16 |

Table 4.1: Physical and thermal parameters used in simulation [21]

4.3 Simulation Results:

The simulation was done at different inlet temperatures and were compared with experimental results. The CFD simulations were performed considering 3-D transient turbulent flow ( k-ε model).

(a) Inlet temperature 32.2$^0$C

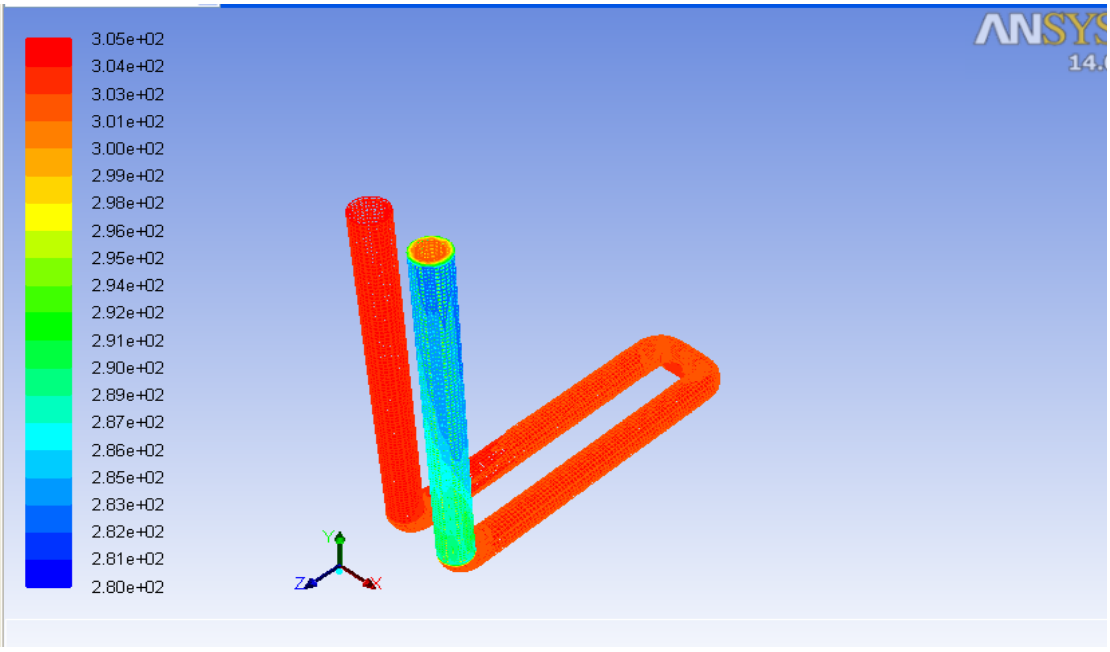


Fig 4.3: Temperature contour at 32.2$^0$C inlet temperature

(b) Inlet temperature 35.3$^0$C

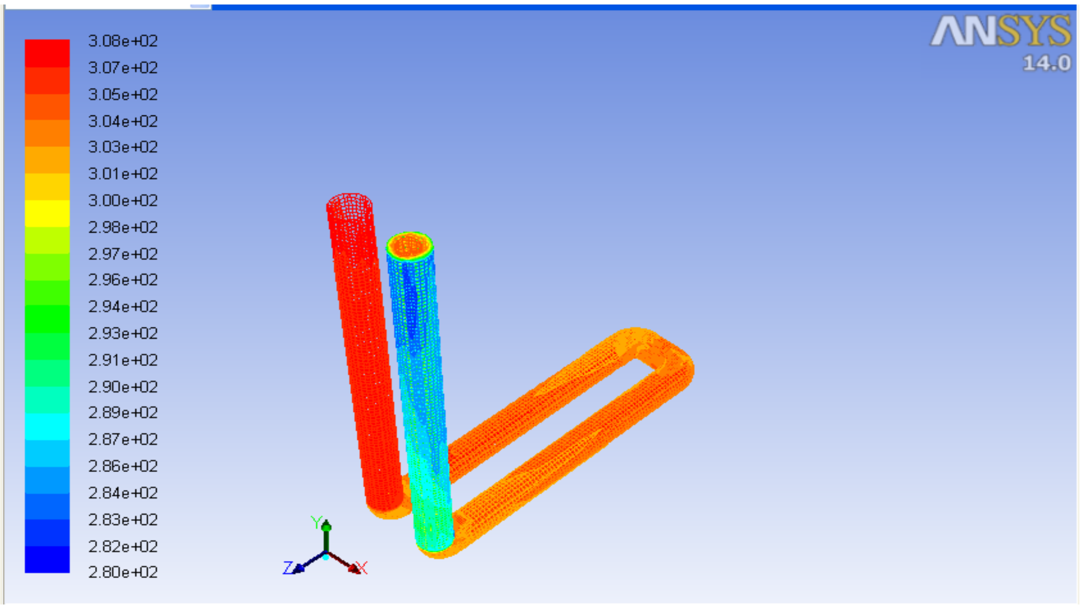


Fig 4.4: Temperature contour at 35.3$^0$C inlet temperature

(c) Inlet temperature 36.8$^0$C

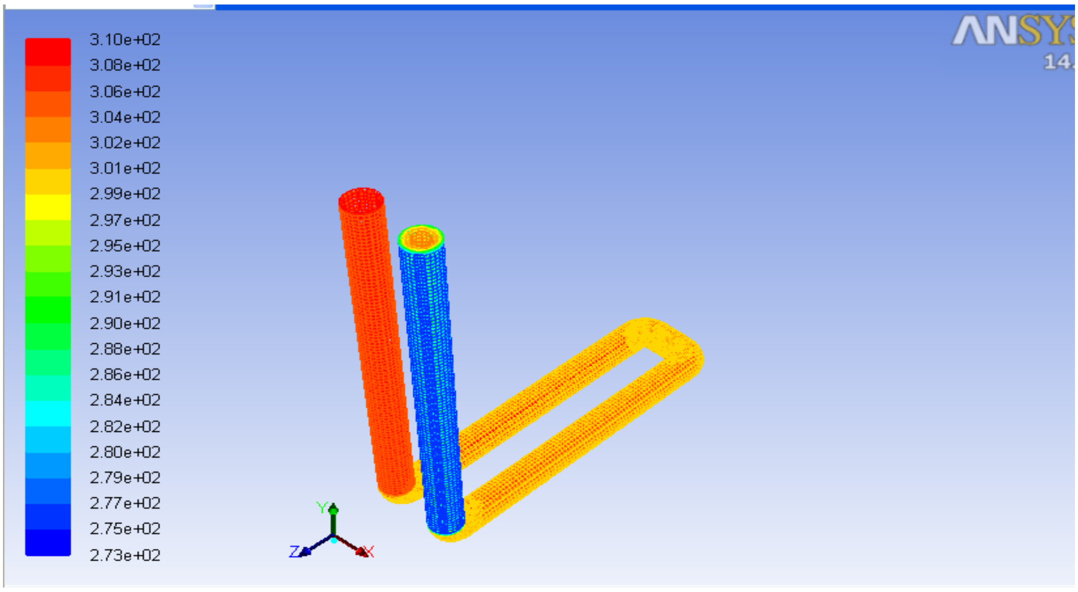


Fig 4.5: Temperature contour at 36.8$^0$C inlet temperature

(d) Inlet temperature 41.5$^0$C

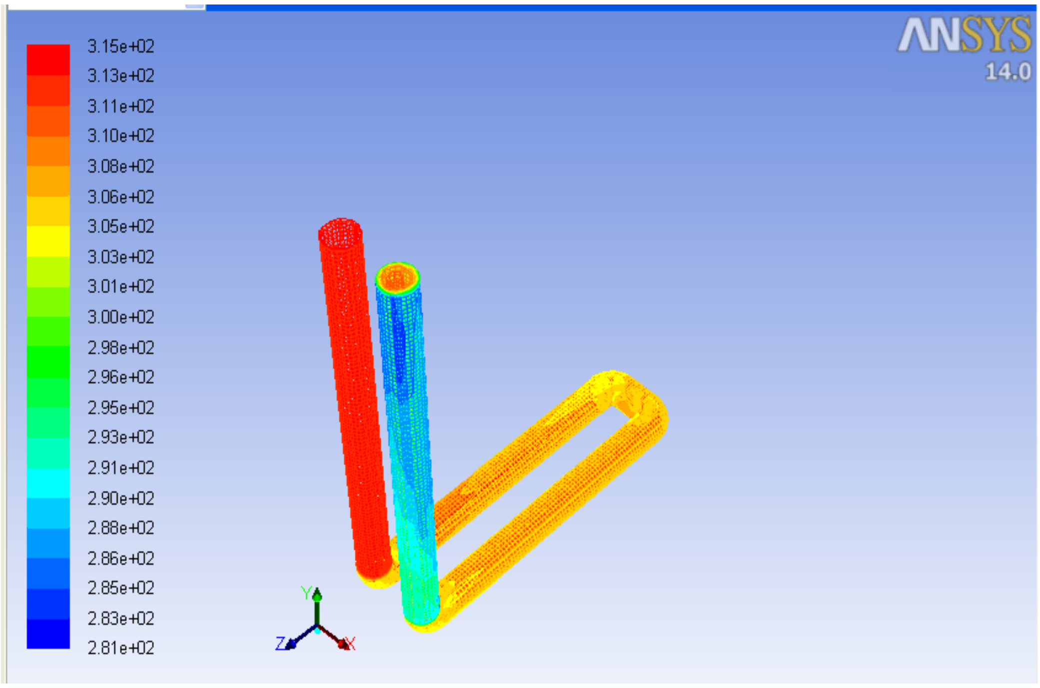


Fig 4.6: Temperature contour at 43$^0$C inlet temperature

(e) Inlet temperature $42.9^0C$

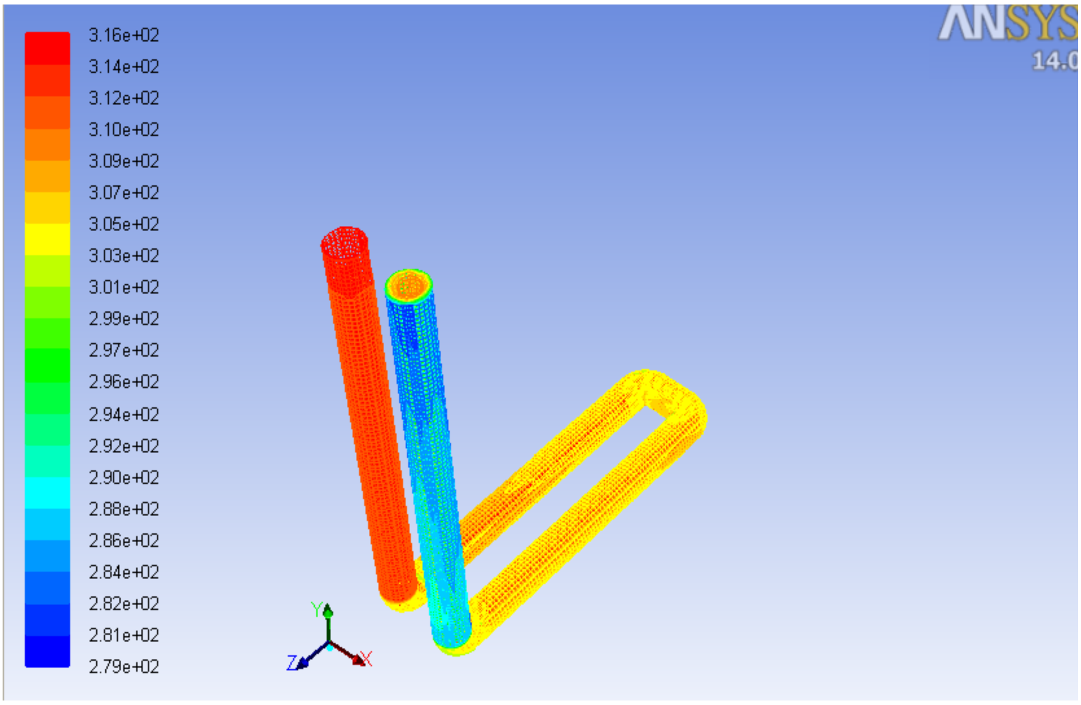


Fig 4.7: Temperature contour at $42.9^0C$ inlet temperature

# CHAPTER 5
# EXPERIMENTAL SET UP

## 5.1 DESCRIPTION OF THE SET-UP

For the experimental work we used PVC pipe of 15 cm diameter and was buried at a depth of 3.65 meters. A blower was used to drive the air through the pipe which was circulated throughout the pipe. A vane type anemometer and thermistor was used to measure the velocity and temperature of the air respectively. The thermistor was attached with the rope, which was moved inside the pipe and the readings were taken at a distance of 1 meter in the pipe.

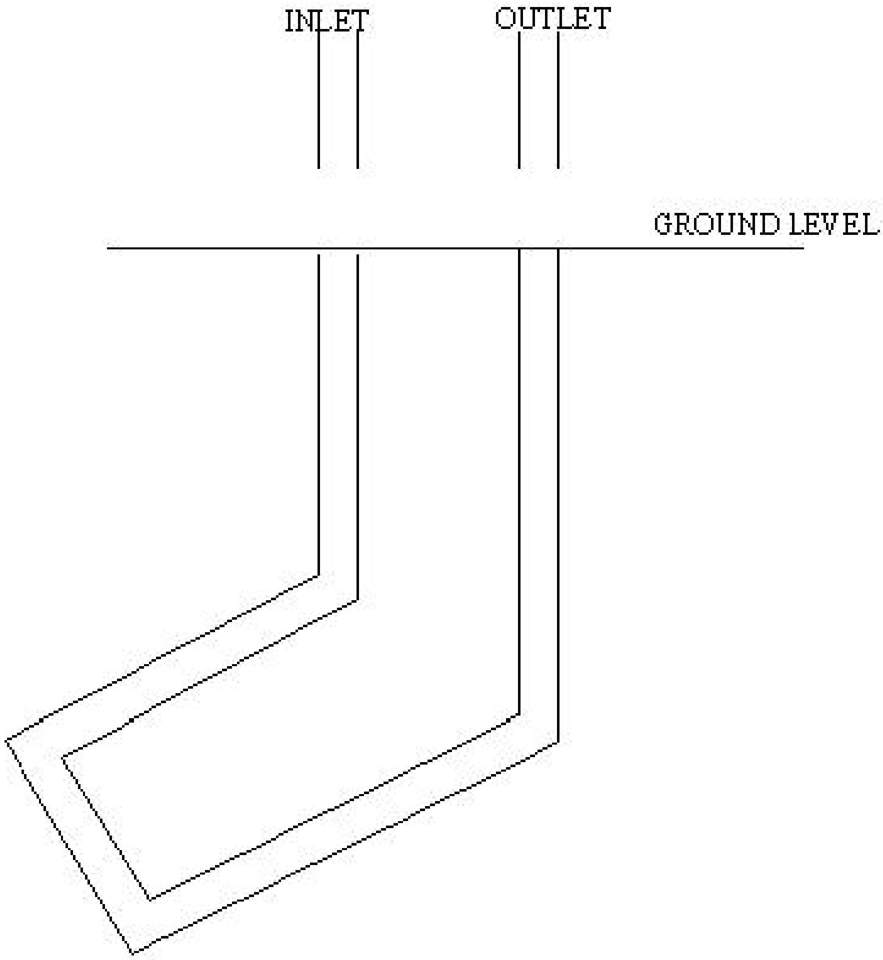


Figure 5.1: Schematic Representation of Experimental Set up

The experimental set-up in the figure 5.1 consists of the 15 cm diameter PVC pipe buried below the ground level at a depth of 3.65 m. At a depth of 3.65 m, the pipe is spread horizontally for a length of 6.3 m. The total length of the experimental set-up is 13.6 m.

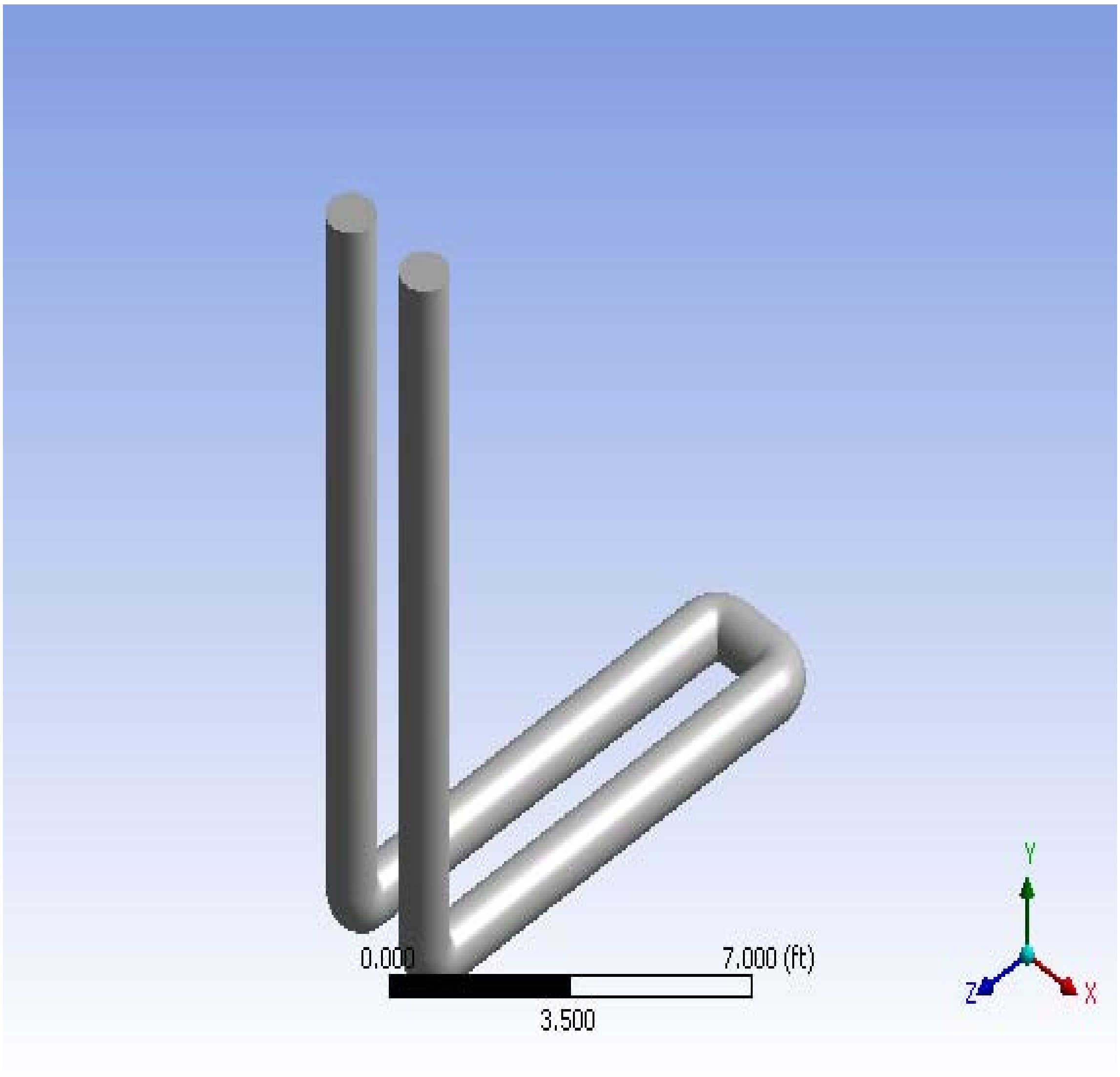


Figure 5.2: 3D view of the experimental set up

Figure 5.3: Experimental set up

The figure 5.3 is before the installation in the trench. The outlet pipe is covered with a sheet which acts as a insulation and prevents any variation in the air coming through the outlet pipe and four L bends have been used in the experimental set up.

Figure 5.4: Experimental Set-Up after installation in trench.

**5.2 PROCEDURE FOR EXPERIMENTATION:**

To start the experimentation, the blower was switched on and the air was let to pass through the pipe for some time till the steady state was achieved. The velocity at the inlet and outlet was calculated with the help of vane type anemometer. The thermistors were attached with the rope which was moved inside the set-up and marking was done on the wire of the thermistor at a gap of 1 meter. The thermistors are attached with temperature auto scanner which continuously displays the readings of thermistor.

The above procedure was repeated with different ambient conditions, this is achieved by conducting the experiment over a span of several weeks. All the data thus obtained is compiled into a single table. The graphs are plotted for various sets of observations obtained from the experiment.

The total cooling has been calculated for flow velocities 1.8, 2.3, 3.0, 3.5 and 4.1 m/s by the following equation:

$$Qc = mC_dC_p(T_{inlet} - T_{outlet}) \quad (1)$$

where m= mass flow rate of air through the pipe

$C_p$= specific heat capacity of air

$C_d$= coefficient discharge of the pipe = 0.6

$T_{inlet}$= inlet temperature of air

$T_{outlet}$= outlet temperature of air.

Coefficient of performance (COP) of the system has been calculated from the following expression:

$$COP = \frac{mC_dC_p(T_{inlet} - T_{outlet})}{\text{Power Input}} \qquad (2)$$

**5.3 INSTRUMENTS USED:**

1. **Anemometer:** Vane type anemometer was used for measuring the velocity of the air. A vane anemometer which uses a small fan is turned by air flowing over the vanes. The speed of the fan is measured by a revolutions counter and converted to a wind speed by an electronic chip. Hence, volumetric flow rate may be calculated if the cross-sectional area is known.


Figure 5.5: Vane type Anemometer

It has 13mm LCD display screen and temperature range is from $0^0$C to $50^0$C. It is extremely light weight instrument weighing 260 g and velocity range is from 0.40 m/s to 45 m/s with an accuracy of ±0.2% + 0.1 m/s.

2. **Thermistors:** It was used for measuring the temperature of the air. It has 1.5 g mass and operating temperature range -25 to $100^0$C.

.

Figure 5.6: Screw Threaded Thermistor

3. **Temperature Auto Scanner:** It displays the temperature encountered by the thermistor attached with the instrument.

| | |
|---|---|
| DISPLAY | 4-1/2 Digit, Segment; 0.56" Height; Red L.E.D |
| ACCURACY | 1% of full scale or ± 10 % $2^0$C |
| RESOLUTION | $0.01^0$C up to $200^0$C |

| | |
|---|---|
| SENSOR BREAK PROTECTION | Display Starts Blinking |
| POWER SUPPLY | 180-230 V AC |
| NO. INPUT CHANNEL | 10 |
| DIMENSIONS | 96 x 96 x 130 mm |

Table 5.1: Specifications of Temperature Auto Scanner


Figure 5.7: Temperature Auto Scanner

4. **Blower:**

Figure 5.8: Blower

**Specifications:**

| | |
|---|---|
| Input Voltage | 220 – 240 V |
| Wattage | 125 W |
| Motor | Class B (Blower type Motor) |
| RPM | 1800 |

Table 5.2: Specifications of Blower

# CHAPTER 6

# CALCULATIONS

Diameter, d = 0.152m

Area = $\pi$ x $d^2/4$= 0.01813 $m^2$

Density of air = 1.225 $kg/m^3$

Specific heat capacity of air, $C_p$= 1006 J/kg K

Coefficient of discharge of pipe, $C_d$ = 0.6 [21]

Total cooling, Qc = $mC_dC_p(T_{inlet} - T_{outlet})$

Mass flow rate, m = density x area x velocity

Power Input = 125 W

Coefficient of Performance, COP = = $mC_dC_p(T_{inlet} - T_{outlet})$/Power Input

Energy efficiency ratio, EER = 3.412 COP [22]

1. Inlet temperature, $T_{inlet}$: 30.6$^0$C

   Outlet temperature, $T_{outlet}$: 29.3$^0$C

   Velocity at outlet: 1.8 m/s

   Qc = 31.36 W

   COP = 0.25

   EER = 0.853

2. Inlet temperature, $T_{inlet}$: 32.2$^0$C

   Outlet temperature, $T_{outlet}$: 30.3$^0$C

   Velocity at outlet: 4.1 m/s

   Qc = 104.43 W

   COP = 0.835

   EER = 2.85

3. Inlet temperature, $T_{inlet}$: 35.3$^0$C

   Outlet temperature, $T_{outlet}$: 29.4$^0$C

   Velocity at outlet: 4.1 m/s

   Qc = 324.28 W

   COP = 2.59

   EER = 8.85

4. Inlet temperature, $T_{inlet}$: 36.8$^0$C

   Outlet temperature, $T_{outlet}$: 29.5$^0$C

   Velocity at outlet: 1.8 m/s

   Qc = 176.14 W

   COP = 1.4

   EER = 4.81

5. Inlet temperature, $T_{inlet}$: 41.5$^0$C

   Outlet temperature, $T_{outlet}$: 30.6$^0$C

   Velocity at outlet: 4.1 m/s

   Qc = 599.1 W

   COP = 4.79

   EER = 16.35

6 Inlet temperature, $T_{inlet}$: 42.9$^0$C

Outlet temperature, $T_{outlet}$: 31.1$^0$C

Velocity at outlet: 1.8 m/s

Qc = 284.74 W

COP = 2.27

EER = 7.75

7 Inlet temperature, $T_{inlet}$: 43$^0$C

Outlet temperature, $T_{outlet}$: 31.5$^0$C

Velocity at outlet: 3.5 m/s

Qc = 539.5 W

COP = 4.31

EER = 14.72

8 Inlet temperature, $T_{inlet}$: 43.2$^0$C

Outlet temperature, $T_{outlet}$: 31.3$^0$C

Velocity at outlet: 3 m/s

Qc = 478.58 W

COP = 3.82

EER = 13.1

9 Inlet temperature, $T_{inlet}$: 43.7$^0$C

Outlet temperature, $T_{outlet}$: 32.2$^0$C

Velocity at outlet: 2.3 m/s

Qc = 354.58 W

COP = 2.83

EER = 9.67

# CHAPTER 7

# EXPERIMENTAL RESULTS

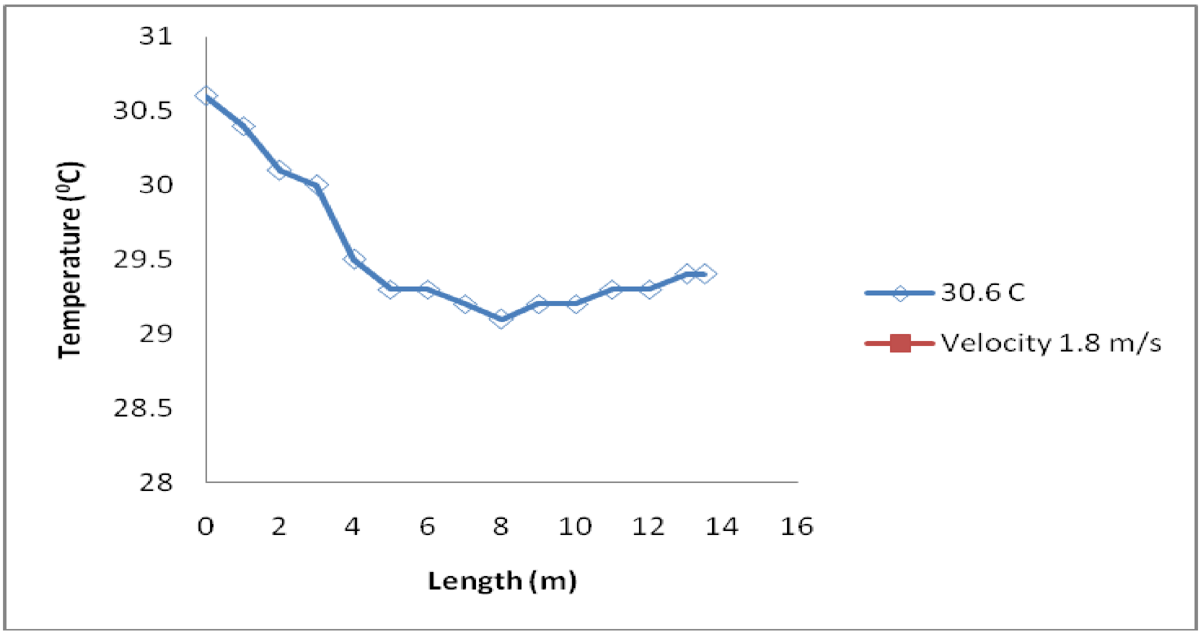


Figure 7.1: Variation of temperature with 30.6 $^0$C inlet temperature.

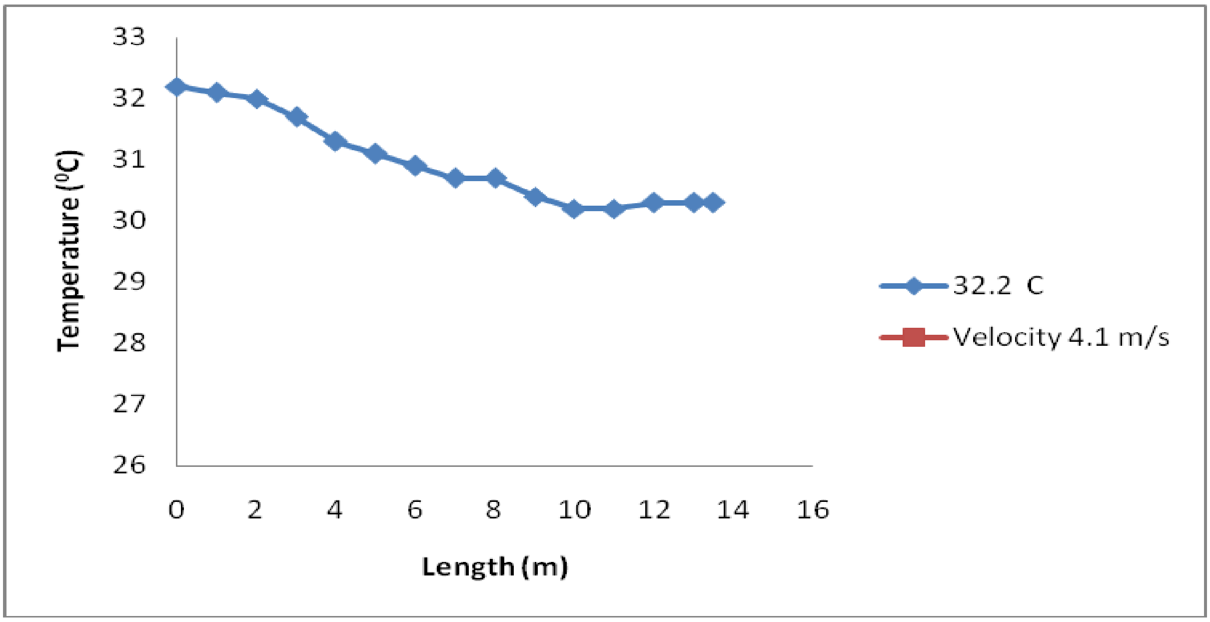


Figure 7.2: Variation of temperature with 32.2 $^0$C inlet temperature.

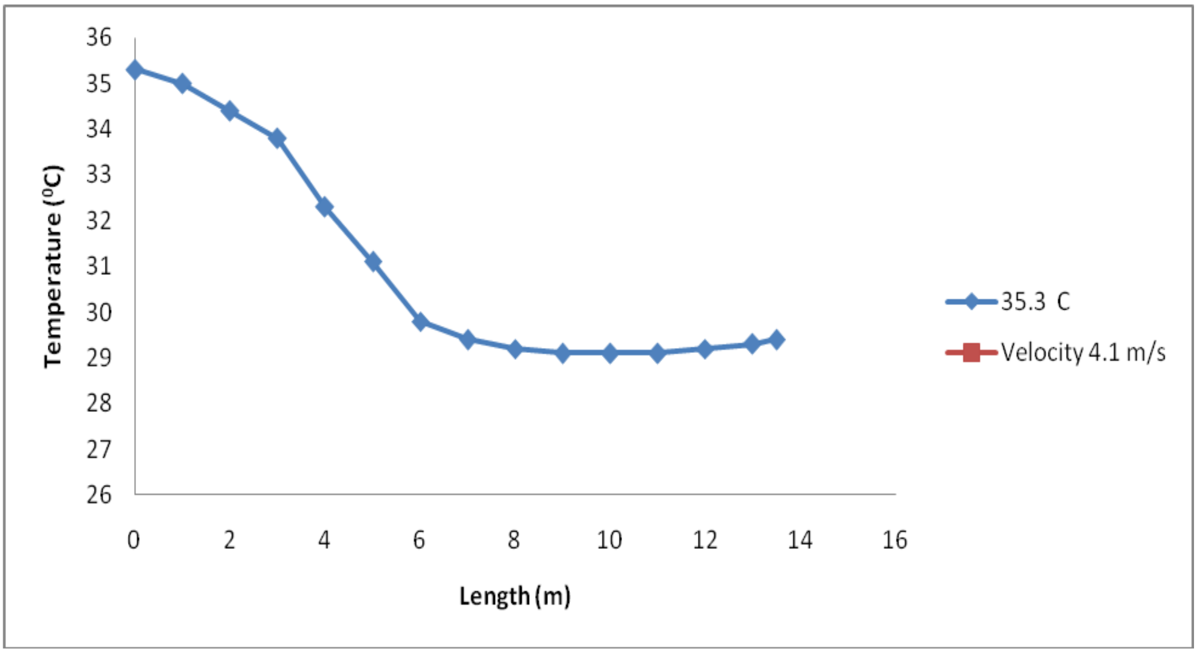


Figure 7.3: Variation of temperature with 35.3$^0$C inlet temperature.

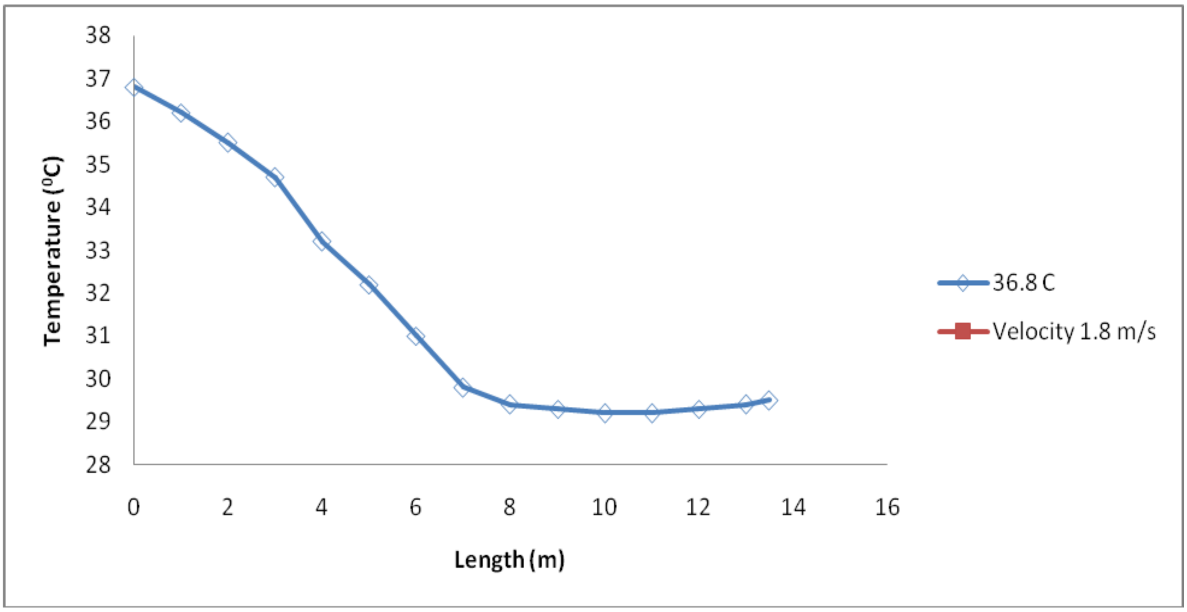


Figure 7.4: Variation of temperature with 36.8$^0$C inlet temperature.

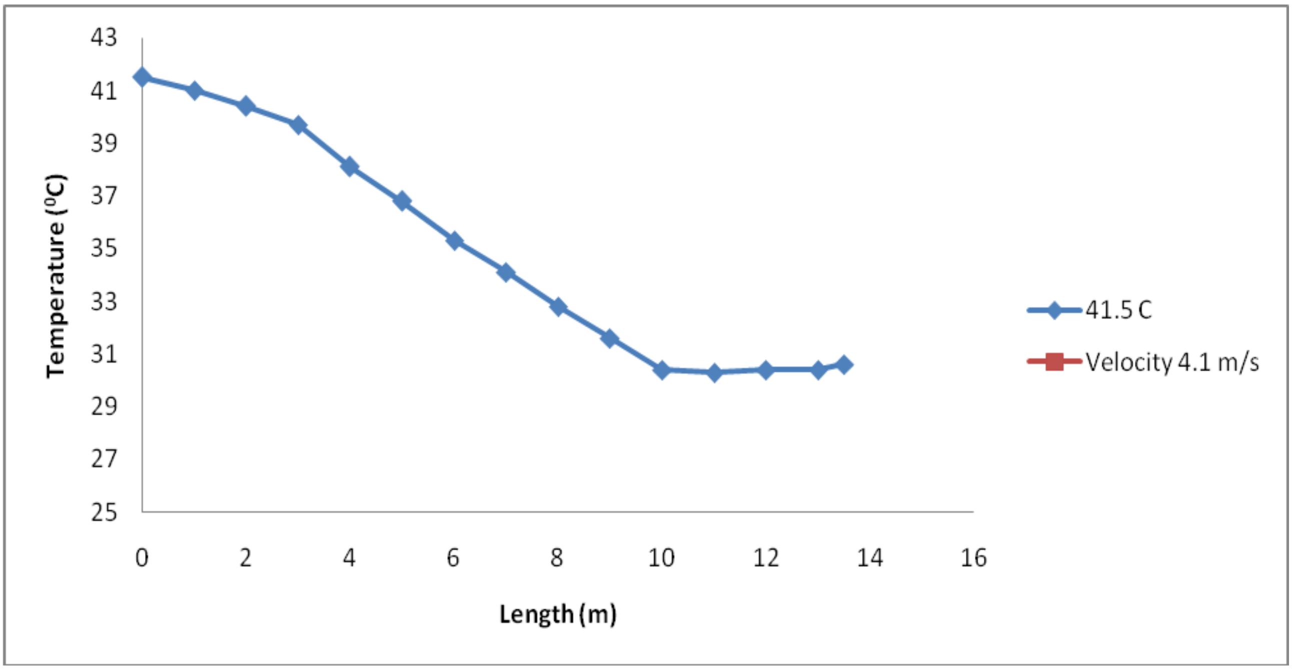


Figure 7.5: Variation of temperature with 41.5$^0$C inlet temperature.

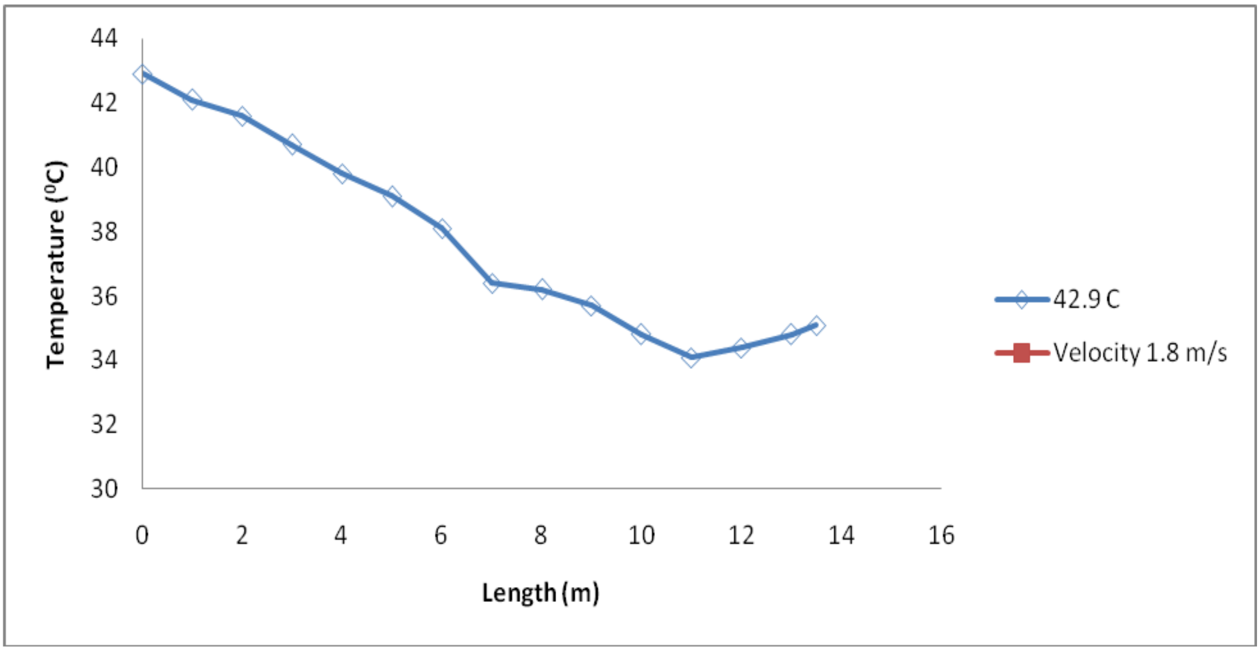


Figure 7.6: Variation of temperature with 42.9$^0$C inlet temperature.

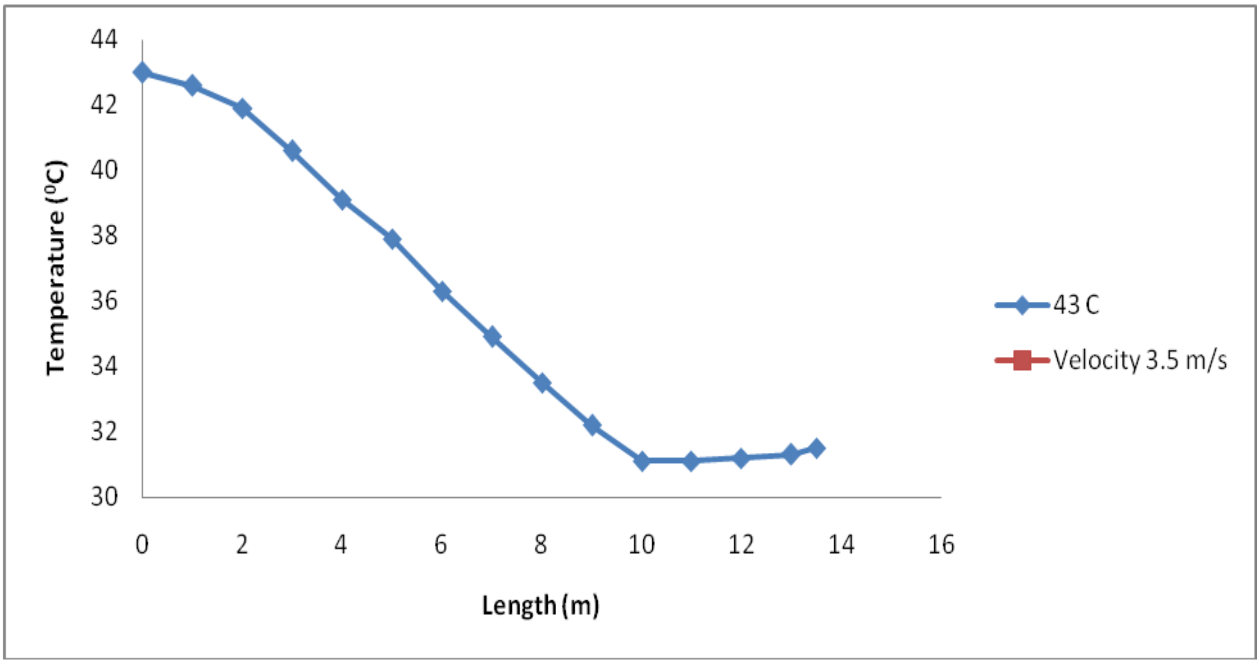


Figure 7.7: Variation of temperature with $43^0$C inlet temperature.

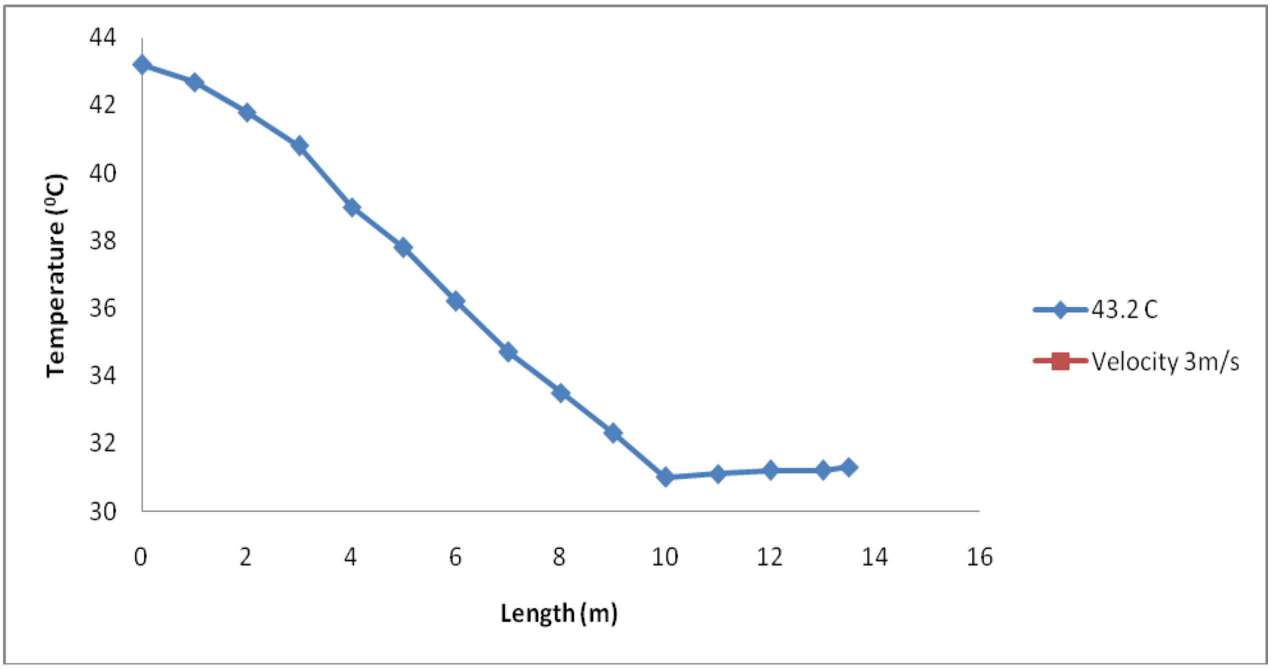


Figure 7.8: Variation of temperature with $43.2^0$C inlet temperature

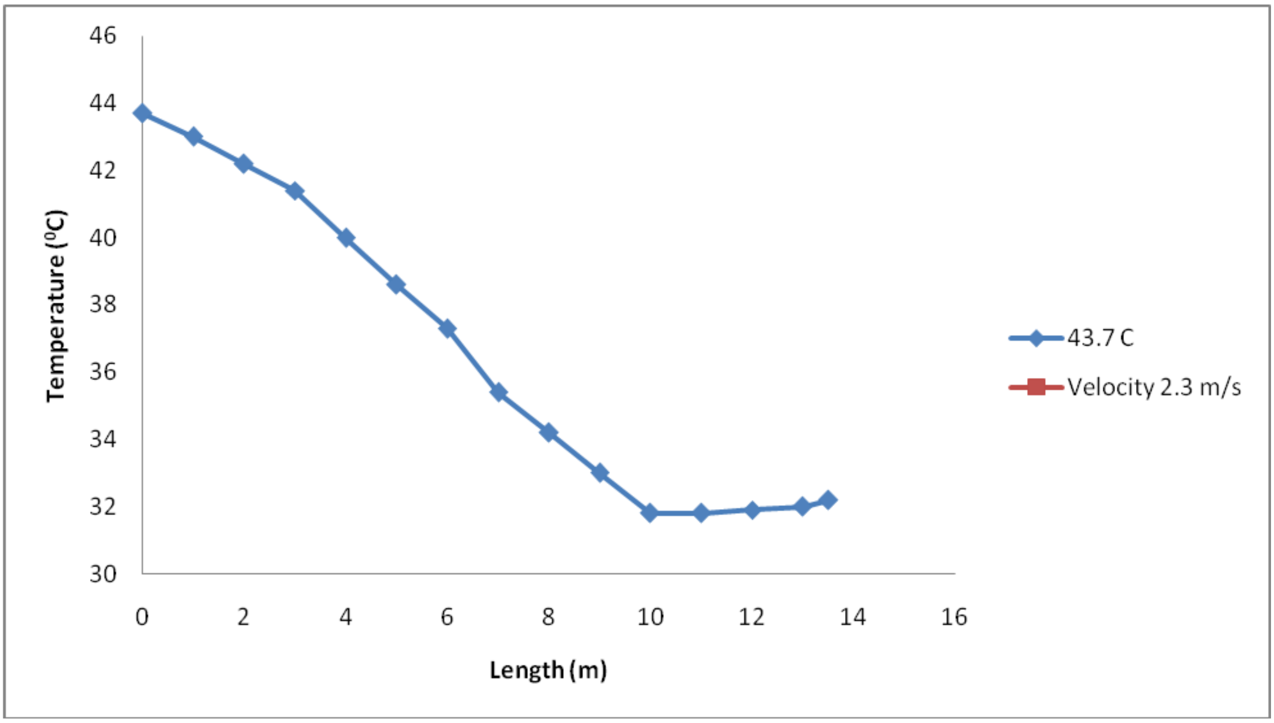


Figure 7.9: Variation of temperature with 43.7 $^{0}$C inlet temperature

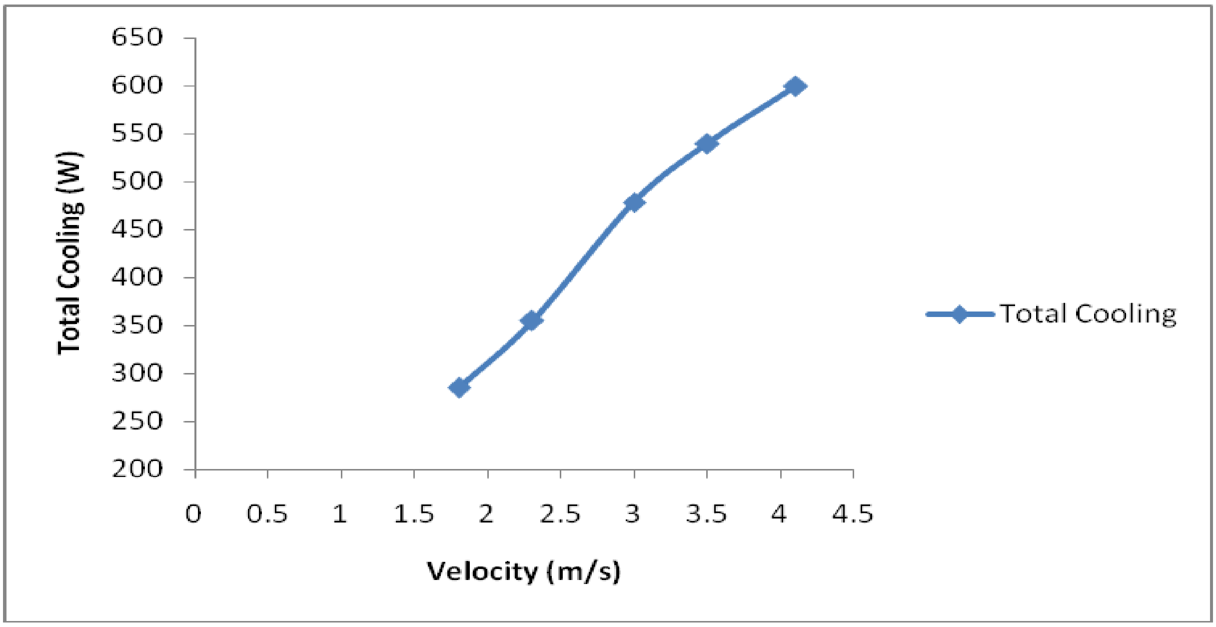


Figure 7.10: Variation of Total Cooling(W) against the velocity

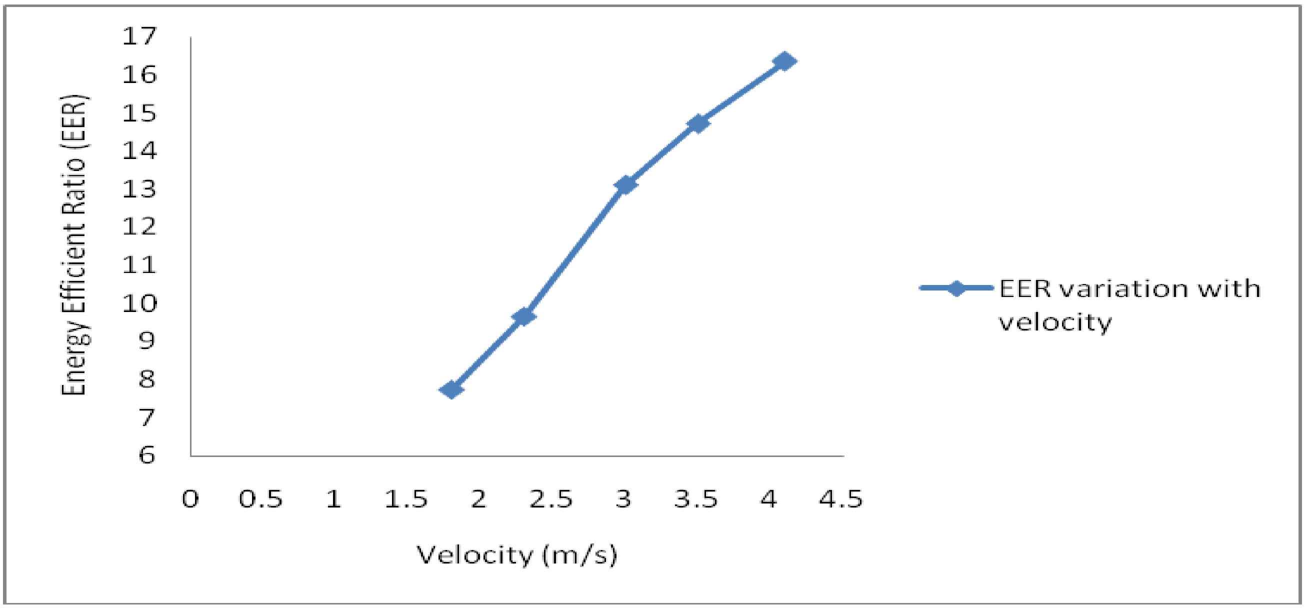


Figure 7.11: Variation of EER against the velocity

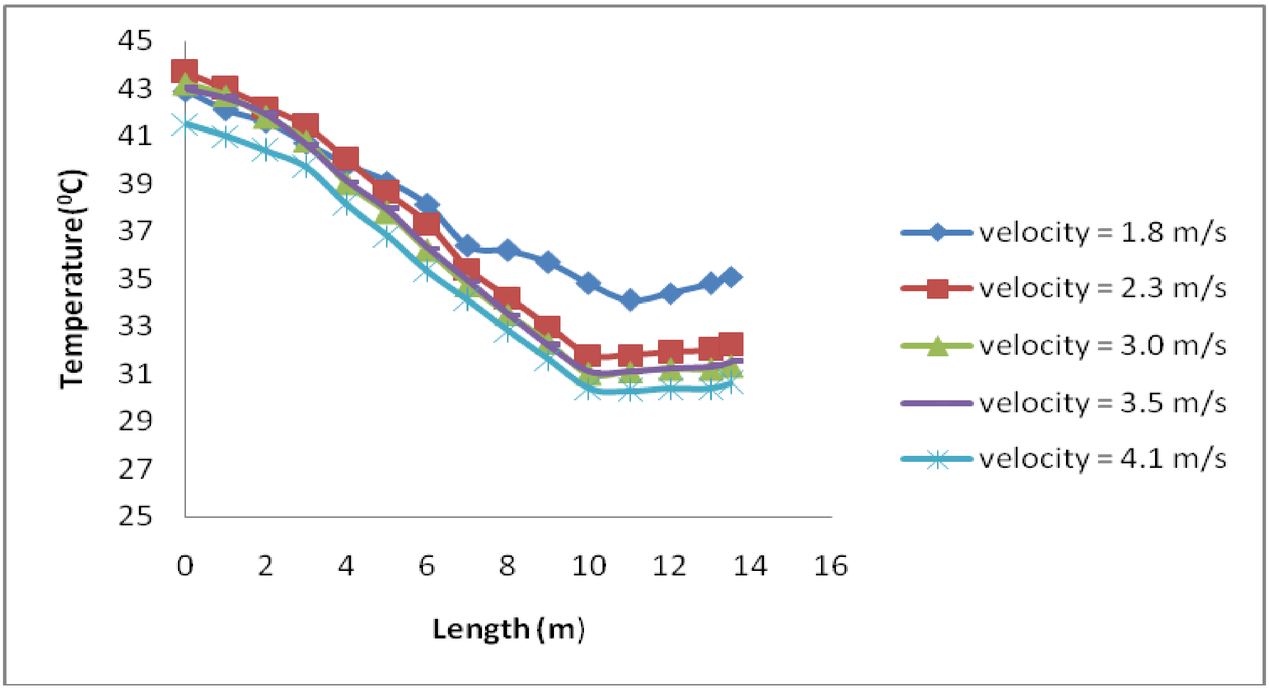


Figure 7.12: Temperature variation along the length of pipe for various exit velocities

## 7.2 INVESTMENT AND ENERGY CONSUMPTION:

i. 6” Pipe of length 13.6m = Rs 3825
ii. Number of bends, 4 = Rs 360
iii. Cost of Blower = Rs 1500
iv. Excavation Cost = Rs 2400

TOTAL= Rs 8085/-

Energy consumption for 120 days and 8 hours daily usage:
Total Operating Hours = 120 days x 8 hrs
= 960 hrs/ year.

Watt usage per hour = 125 W

Electricity Cost per Kwh = Rs 6

Total Energy Consumption = 960 x 125/ 1000
= 120 x 6
= Rs 7200 per year.

# CHAPTER 8

# VALIDATION

The experimental results have been obtained for different inlet temperatures at different velocities. Then the theoretical values are obtained using Ansys software for corresponding air inlet temperature and corresponding velocity of the air. The two sets of the data, that is, theoretical and experimental are plotted on the same graph. The graphs show the difference between the theoretically expected values and the experimental values.

The theoretically calculated values are plotted along with the experimental values obtained from the experimental observations obtained from the site. The two curves are shown on the same graph to allow easy comparison between the two. The graphs corresponding to the various inlet air temperatures as shown below:

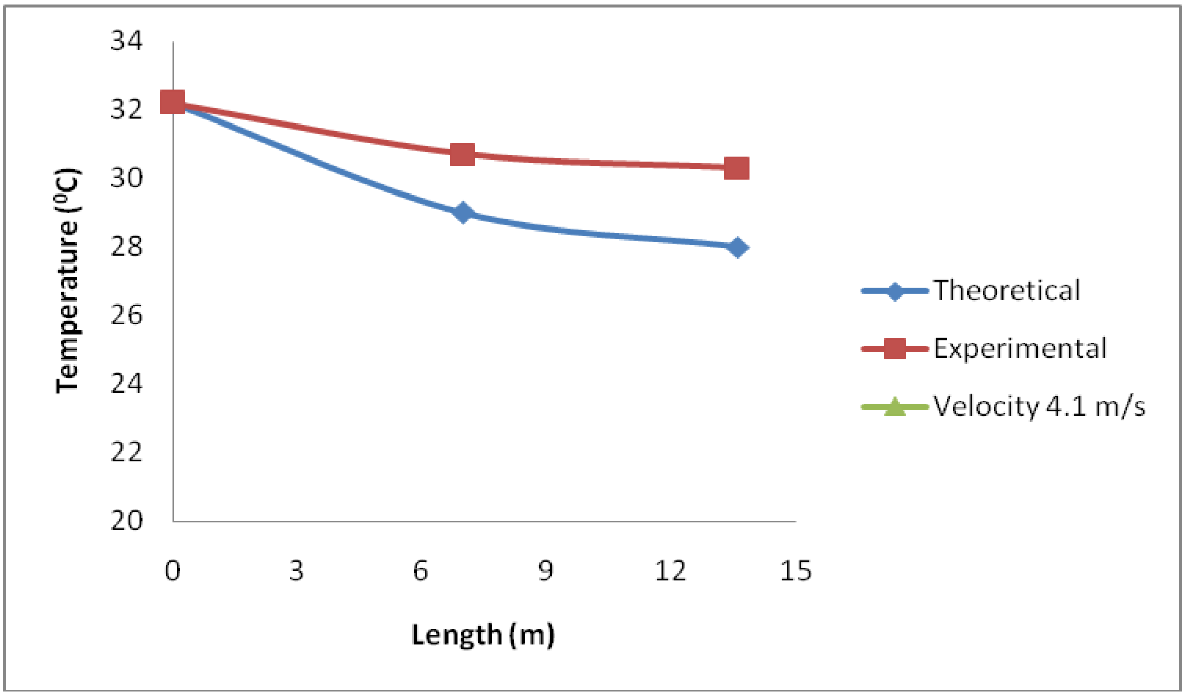


Fig 8.1: Comparison of results at 32.2 $^{0}$C inlet temperature

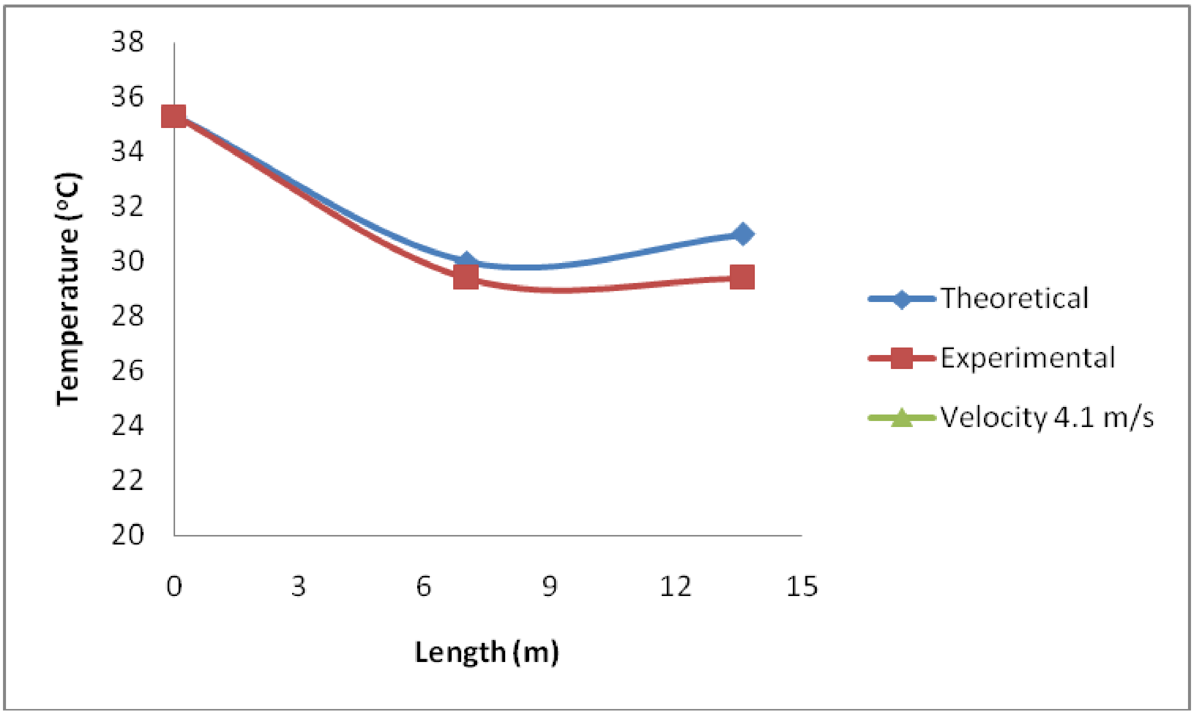


Fig 8.2: Comparison of results at 35.3 $^{0}$C inlet temperature

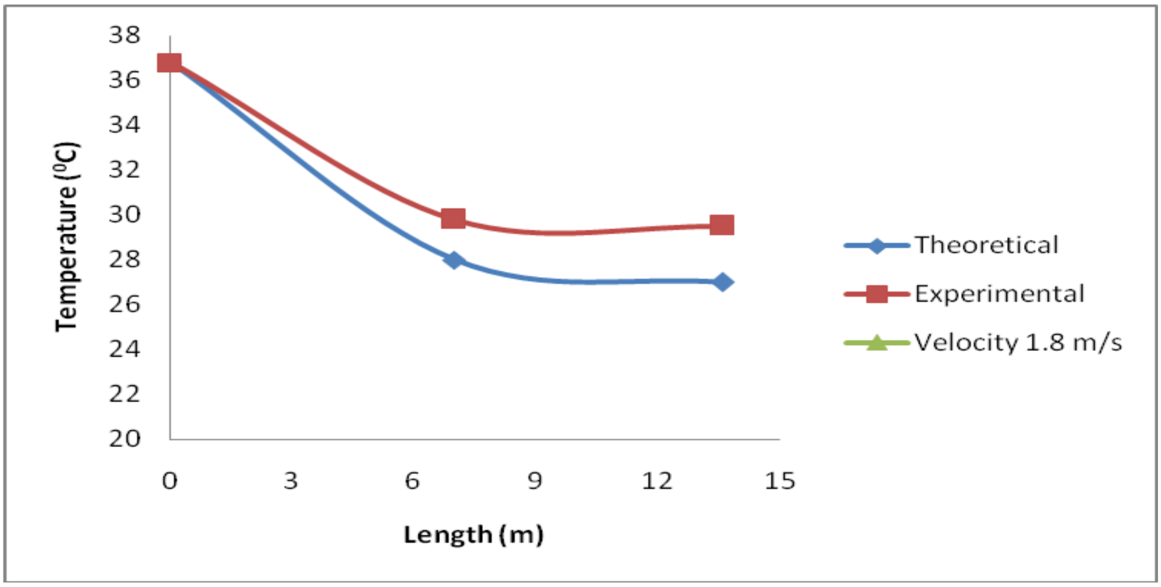


Fig 8.3: Comparison of results at 36.8$^{0}$C inlet temperature

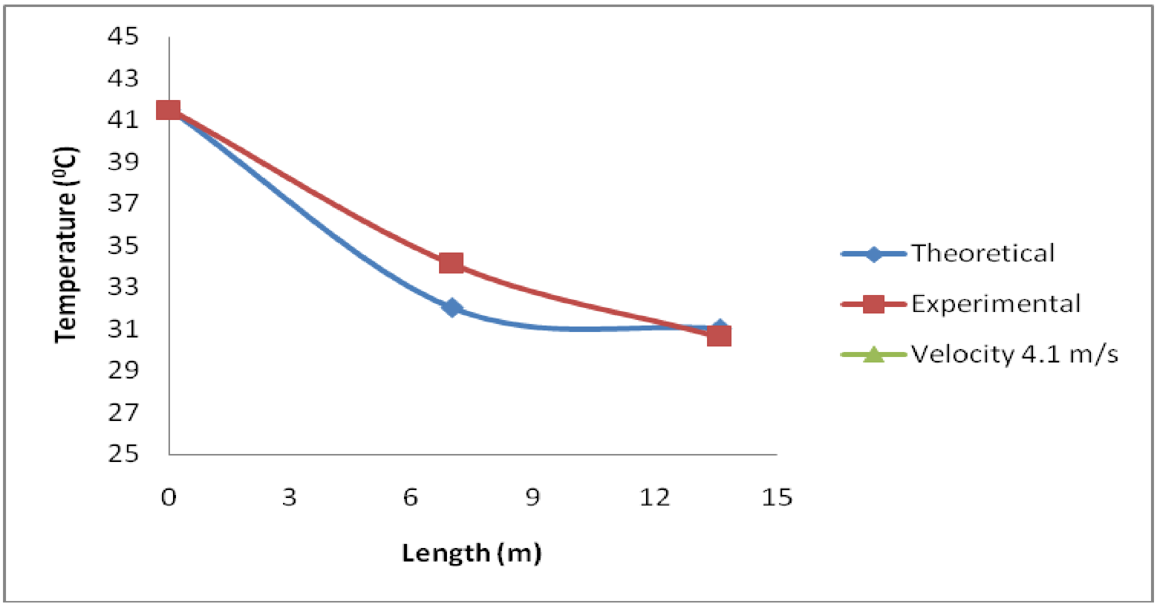


Fig 8.4: Comparison of results at 41.5$^0$C inlet temperature

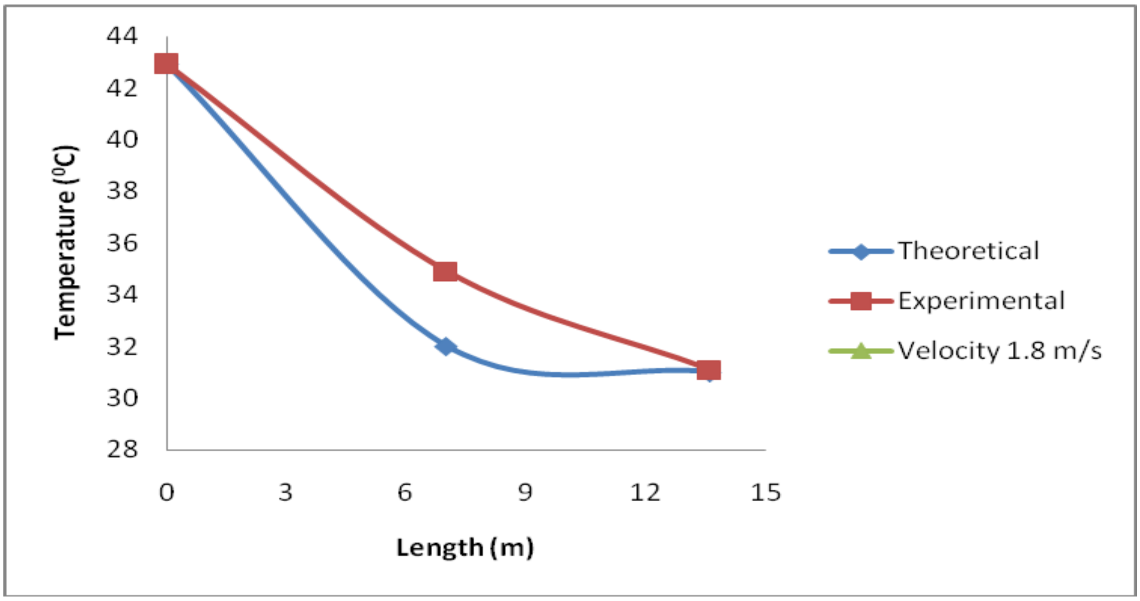


Fig 8.5: Comparison of results at 42.9$^0$C inlet temperature

# CHAPTER 9
# CONCLUSION

## 9.1 Explanation of the results:

After going through the comparison charts shown in the previous chapter, we can see that the results are quite encouraging. The results are summarized under the following points:

- For the pipe of 13.6 m length and 0.15 m diameter, temperature rise of $5.9^0$C-$11.9^0$C has been observed for the outlet flow velocity ranging from 1.8 m/s to 4.1 m/s.
- At lower speed of 1.8 m/s, greater temperature difference is obtained but in terms of cooling obtained, it is optimal to use at 4.1 m/s.
- The COP of the system varies from 2.2 – 4.7 for increase in outlet velocity from 1.8 m/s to 4.1 m/s.
- The results also show that conduction plays very important role in the cooling of air, it is evident from the fact that temperature remains constant where the insulation is done.
- At higher outlet velocity and maximum temperature difference, the system is most efficient to be used.
- The system is not efficient to use at a temperature less than $35^0$C.
- The energy efficient ratio (EER) of the system varies in the range of 4.81 to 16.3.
- The maximum EER 16.3 is obtained at temperature difference of $10.9^0$C and outlet velocity of 4.1 m/s.

This work can be used as a design tool for the design of such systems depending upon the requirements and environmental variables. The work can aid in designing of such systems with flexibility to choose different types of pipes, different dimensions of pipes, different materials and for different ambient conditions. So this provides option of analyzing wide range of combinations before finally deciding upon the best alternative in terms of the dimension of the pipe, material of the pipe, type of fluid to be used.

### 9.2 Scope for future work:

- The blower with variable running speed should be used.
- Theoretical model should be developed to predict the temperature of soil per meter depth of soil and affect of moisture content in the soil.
- This system will be tested for winter heating.
- For further study humidity control mechanism should be incorporated.
- The fluid dynamics studies should be conducted to minimize the flow losses in the pipe and effect of moisture to be studied.
- Since the power consumption of the set-up is very low for normal loads, it can be driven by using solar energy. This will help in eliminating the consumption of any type of energy required for running this system.

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INLET TEMPERATURE: 30.6$^0$C INLET VELOCITY: 7 m/s

OUTLET VELOCITY: 1.8 m/s

| Length (m) | Temperature ($^0$C) |
|---|---|
| 1 | 30.4 |
| 2 | 30.1 |
| 3 | 30.0 |
| 4 | 29.5 |
| 5 | 29.3 |
| 6 | 29.3 |
| 7 | 29.2 |
| 8 | 29.1 |
| 9 | 29.2 |
| 10 | 29.2 |
| 11 | 29.3 |
| 12 | 29.3 |
| 13 | 29.3 |
| Outlet | 29.3 |

Table A1: Temperature Variation along the length at 30.6$^0$C

INLET TEMPERATURE: $32.2^0C$ INLET VELOCITY: 11 m/s

OUTLET VELOCITY: 4.1 m/s

| Length (m) | Temperature ($^0C$) |
|---|---|
| 1 | 32.2 |
| 2 | 32.0 |
| 3 | 31.7 |
| 4 | 31.3 |
| 5 | 31.1 |
| 6 | 30.9 |
| 7 | 30.7 |
| 8 | 30.7 |
| 9 | 30.4 |
| 10 | 30.2 |
| 11 | 30.2 |
| 12 | 30.1 |
| 13 | 30.3 |
| Outlet | 30.3 |

Table A2: Temperature Variation along the length at $32.2^0C$

INLET TEMPERATURE: $35.3^0C$ INLET VELOCITY: 11 m/s

OUTLET VELOCITY: 4.1 m/s

| Length (m) | Temperature ($^0C$) |
|---|---|
| 1 | 35.0 |
| 2 | 34.4 |
| 3 | 33.8 |
| 4 | 32.3 |
| 5 | 31.1 |
| 6 | 29.8 |
| 7 | 29.4 |
| 8 | 29.2 |
| 9 | 29.1 |
| 10 | 29.1 |
| 11 | 29.1 |
| 12 | 29.2 |
| 13 | 29.3 |
| Outlet | 29.4 |

Table A3: Temperature Variation along the length at $35.3^0C$

INLET TEMPERATURE: 36.8$^0$C INLET VELOCITY: 7 m/s

OUTLET VELOCITY: 1.8 m/s

| Length (m) | Temperature ($^0$C) |
|---|---|
| 1 | 36.2 |
| 2 | 35.5 |
| 3 | 34.7 |
| 4 | 33.2 |
| 5 | 32.2 |
| 6 | 31.0 |
| 7 | 29.8 |
| 8 | 29.4 |
| 9 | 29.3 |
| 10 | 29.2 |
| 11 | 29.2 |
| 12 | 29.3 |
| 13 | 29.4 |
| Outlet | 29.5 |

Table A4: Temperature Variation along the length at 36.8$^0$C

INLET TEMPERATURE: $41.5^0C$ INLET VELOCITY: 11 m/s

OUTLET VELOCITY: 4.1 m/s

| Length (m) | Temperature ($^0C$) |
|---|---|
| 1 | 41.0 |
| 2 | 40.4 |
| 3 | 39.7 |
| 4 | 38.1 |
| 5 | 36.8 |
| 6 | 35.3 |
| 7 | 34.1 |
| 8 | 32.8 |
| 9 | 31.6 |
| 10 | 30.4 |
| 11 | 30.3 |
| 12 | 30.4 |
| 13 | 30.4 |
| Outlet | 30.6 |

Table A5: Temperature Variation along the length at $41.5^0C$

INLET TEMPERATURE: 42.9$^0$C INLET VELOCITY: 7 m/s

OUTLET VELOCITY: 1.8 m/s

| Length (m) | Temperature ($^0$C) |
|---|---|
| 1 | 42.1 |
| 2 | 41.5 |
| 3 | 40.6 |
| 4 | 39.2 |
| 5 | 38.0 |
| 6 | 36.5 |
| 7 | 34.9 |
| 8 | 33.3 |
| 9 | 31.9 |
| 10 | 30.6 |
| 11 | 30.7 |
| 12 | 30.7 |
| 13 | 30.9 |
| Outlet | 31.1 |

Table A6: Temperature Variation along the length at 42.9$^0$C

INLET TEMPERATURE: $43^0C$ INLET VELOCITY: 10 m/s

OUTLET VELOCITY: 3.5 m/s

| Length (m) | Temperature ($^0C$) |
|---|---|
| 1 | 42.6 |
| 2 | 41.9 |
| 3 | 40.6 |
| 4 | 39.1 |
| 5 | 37.9 |
| 6 | 36.3 |
| 7 | 34.9 |
| 8 | 33.5 |
| 9 | 32.2 |
| 10 | 31.1 |
| 11 | 31.0 |
| 12 | 31.2 |
| 13 | 31.3 |
| Outlet | 31.5 |

Table A7: Temperature Variation along the length at $43^0C$

INLET TEMPERATURE: 43.2$^0$C INLET VELOCITY: 9 m/s

OUTLET VELOCITY: 3.0 m/s

| Length (m) | Temperature ($^0$C) |
|---|---|
| 1 | 42.7 |
| 2 | 41.8 |
| 3 | 40.8 |
| 4 | 39.0 |
| 5 | 37.8 |
| 6 | 36.2 |
| 7 | 34.7 |
| 8 | 33.5 |
| 9 | 32.3 |
| 10 | 31.0 |
| 11 | 31.1 |
| 12 | 31.2 |
| 13 | 31.2 |
| Outlet | 31.3 |

Table A8: Temperature Variation along the length at 43.2$^0$C

INLET TEMPERATURE: 43.7$^0$C INLET VELOCITY: 8 m/s

OUTLET VELOCITY: 2.3 m/s

| Length (m) | Temperature ($^0$C) |
|---|---|
| 1 | 43 |
| 2 | 42.2 |
| 3 | 41.4 |
| 4 | 40.0 |
| 5 | 38.6 |
| 6 | 37.3 |
| 7 | 35.4 |
| 8 | 34.2 |
| 9 | 33.0 |
| 10 | 31.8 |
| 11 | 31.8 |
| 12 | 31.9 |
| 13 | 32.0 |
| Outlet | 32.2 |

Table A9: Temperature Variation along the length at 43.7$^0$C