Case Study of a Hybrid Geothermal-Solar System

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Abstract

The usage and management of renewable energy have become a topic of interest since existing literature suggests that it would replace fossil fuels. In this study, an analysis of a closed-loop hybrid geothermal-solar energy system is introduced to control air temperature. This can be used in different air-conditioning applications including greenhouses, living quarters, and buildings. Such a case study was carried out in Damanhur city, Beheira Governorate, Egypt. First, the air produced from the proposed hybrid system conditioned the air of a room with the dimensions of L 2m x W 2m x H 2m. Geothermal energy was used to transfer heat to/from an air stream flowing inside a 5 m long, 2 inches in diameter, and 5.3 mm thickness PVC pipe. The pipe was buried 2 m below the ground's surface and was supported by a solar chimney during the winter for the natural draft of air stream. In addition, a numerical model was built with 9 closed-loop geothermal cases of different design conditions. The pipe's diameter varied in different cases from 0.17, 0.35, and 0.65 m, while the total pipe length was 47, 64, and 87 m. After that, the air stream was supplied to a room with the dimensions of L 3m x W 3m x H 3m. The air was subject to a 1m long solar chimney at 45^{o} angle on a horizontal plane. The results of the numerical model prove that the maximum room temperature difference, which is close to 5 ^{o}C, can be achieved using a pipe with a diameter of 0.65 m, and a length of 87 m. The validation of the numerical model was carried out using experimental results.

Keywords: Geothermal energy, Solar chimney, Shallow geothermal, Hybrid geothermal solar

1. Introduction

Few decades ago, Renewable energy gained interest for securing a future for energy production, especially considering the continual ramifications of global warming and the energy crisis. Nowadays,

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fossil fuel is the main source of energy but it harms the environment and substantiates global warming. Such a crisis needs effective solutions [1]. Geothermal energy has been used since 3000 BC. Iranians used it to cool underground air tunnels and wind towers [2, 3]. In the 19th century, Wilkinson designed a 500-ft long underground cooling tunnel for 148 barns [4]. Mathur et al [5] performed an experimental study on an inclined roof solar chimney for natural ventilation. The design of the experimental setup is shown in **Fig. 1**, and **Table 1** , the study concluded that flow rate at 45° inclination is about 10% more than flow rate at 30° and 60° inclinations , also increase in air gap and inlet height flow rate increases.

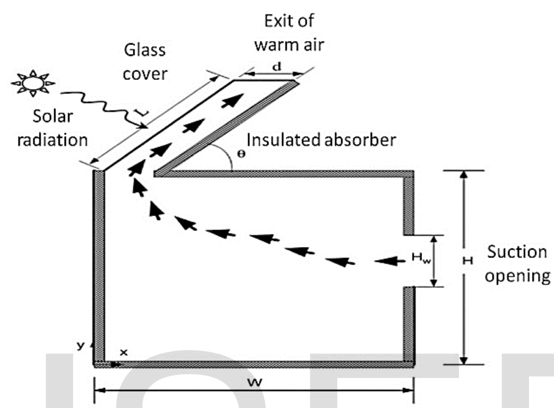

Fig.1. Experimental setup to investigate the performance of inclined solar chimney **[5]**.

Table.1 Variation of optimum inclination of solar chimney **[5]**.

Latitude (°)	The optimum inclination of the solar chimney (°)
0	55
5	50
10	50
15	50
20	45
25	45
30	45
35	50
40	50
45	55
50	55
55	60
60	60
65	60

Ozgener et al [6], carried out an experimental study along with an Exergoeconomic analysis of an underground air tunnel system for usage in a greenhouse cooling system.

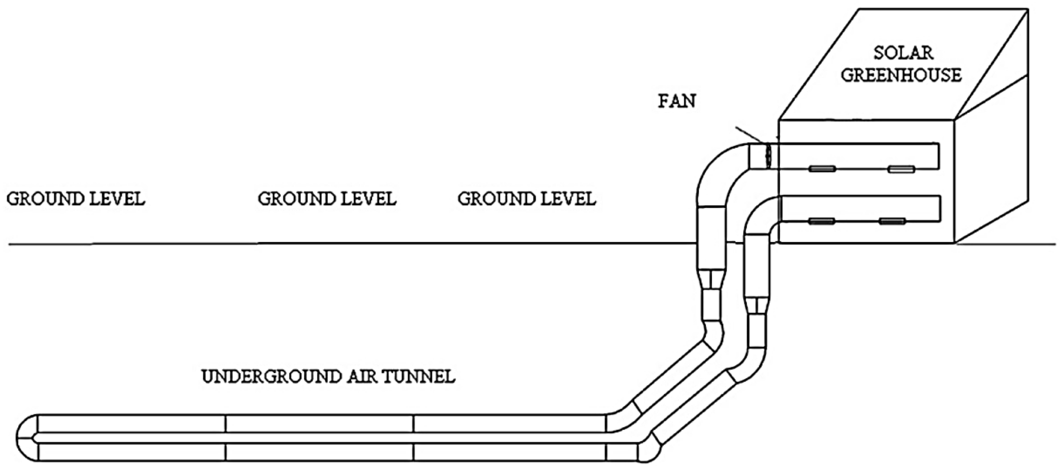

Fig.2. Schematic of experimental set up of the underground air tunnel **[6]**

The system contains a closed loop earth-to-air heat exchanger (underground air tunnel) as shown in **Fig.2.** The buried pipe's diameter was 56 cm, and the length was 47 m long. The greenhouse connection pipe diameter was 80 cm in diameter, and 15 m in length. A blower volumetric airflow rate was 5300m^3/h at a pressure drop of 200Pa. In addition, the power of the electric motor was 736 W and the greenhouse GRP surface area was 48.512 m^2, the study concluded that second-law efficiency values for the underground air tunnel were obtained to be in a range of 56.1-60.5% and the overall second-law efficiency value was found to be 56.9%.

Air conditioning is required for both industrial and general community needs, which can be implemented via a traditional evaporative cooler. However, this may affect the ozone layer because such a method utilizes chlorofluorocarbons (CFC); also known as "Freon". Therefore, many new technologies understudy avoid CFC **[4]**.

Geothermal energy can be used in power generation if a high temperature can be provided. On the other hand, shallow geothermal applications and ground source heat pumps need only moderate to low temperatures. Describe what using geothermal directly for heating/cooling industrial processes, fish farming, swimming pools, bathing, space heating, and agriculture as direct use. Direct use is appropriate for some countries with low enthalpy resources, like Tunisia **[5]**. The geothermal system consists of a working fluid, a reservoir/caprock, and a heat source. At depths from 50 km to 100 km, the heat source is available from rock layers at high temperatures from 900ºC to 1200ºC. High-temperature geothermal resources can be used in power generation [6]. On the other hand, the use of moderate temperature resources along with indirect geothermal applications can be described. Whether it is heating or cooling, it serves as an alternative for fossil fuels as it is much more efficient and much more economical by three times as much as power generation, the study concluded that heating efficiency for paddy drieying of the dryer is 82.5% and total drying efficiency reached 51.1% while local people welcomed the direct using of geothermal technology for drying agricultural products [7].

Overcoming global warming has become a worldwide threat. More than 90 countries identified the geothermal potential to overcome fossil fuels' environmental problems, including global warming. Seventy-two countries worldwide have dedicated their efforts to increasing geothermal utilization, the study concluded that that the use of low-to moderate temperature geothermal resources in direct heat applications, given the right environment, is viable and economic. As oil and gas supplies dwindle and increase in price, geothermal energy will become an even more economically viable alternative source of energy. [8]. The exploitation of geothermal energy remains the main method for using geothermal energy. The direct use of geothermal energy is the most prominent among applied utilities , the study concluded that payback period for the proposed project is around 11-13 years with Government funding support which is sound for a pilot demonstration plant. The project viability is heavily reliant on the quality of the geothermal resource, drilling costs and the effects of various proposed emission trading schemes. All these sensitive variables contribute to the considerable project risks due to the uncertainty surrounding the site specific characteristics of the Yarragadee aquifer and temperature gradients and The results indicate that geothermal absorption cooling for precooling of the gas yields significant savings in the work requirement for hydrogen liquefaction and is more advantageous than using geothermal work output in a liquefaction cycle. [9,10]. With the rise of global warming, shallow geothermal aquifer applications have become a more sustainable alternative, noting that it already has been in use for a long time ago instead of fossil fuel. The aquifer consists of two types of materials; one part is water permeable and the second contains rock or clay as impermeable materials. An aquifer's final point is the sea or lake, in which water flows through the aquifer from top to bottom, the study concluded that that during one cooling period, the seasonal aquifer thermal storage system uses 31% less electrical energy than a cooling tower system. It also consumes none of the water that a cooling tower system uses, which could amount to as much as 116 m3 of water in one cooling period. [11].

Cost-effective solution is an important consideration as consumers tend to notice low-cost affections by applying geothermal principles on food processing fields, greenhouses, aquaculture, and management offices. To add, geothermal energy that is not high in temperature and is extracted from shallow depths costs less than deeper sources. Not to mention that there are additional ramifications relating to reducing air pollution resulting from fossil fuel emissions. The transportation of geothermal heat is not an economic choice as most geothermal resources available are in remote places. Lithium bromide/water system that uses geothermal energy exists for space cooling applications while absorption refrigeration cycles for industrial cooling at approximately -50 ºC use ammonia/water system, the study concluded that that using low-to-moderate temperature geothermal resources in the direct heat applications, given the right conditions, is an economically feasible business, and can make a significant contribution to a country's or region's energy mix. As oil and gas supplies dwindle and increase in price, geothermal energy will become an even more economically viable alternative source of energy. **[12]**.

The benefits of geothermal energy make such energy the preferred choice in greenhouses, such as low-enthalpy energy that is only required in greenhouses. Geothermal energy provides low-enthalpy, which is easy to support thanks to geothermal reservoirs in greenhouses zone. Furthermore, easy installation is required for the heating system. Not to mention that economic costs are major aspects of the project. However, this covers initial costs and generates profits compared to other types of energy sources, like solar energy or fossil fuel. Geothermal energy is available throughout the year and is a reliable strategic energy source in any weather condition. Applying geothermal energy in confined greenhouses can be set using a closed-loop water path through a plastic pipe or air path supported with a fan as a heat exchanger. To support the required air conditioning roots in open areas, a plastic pipe containing water or air path is used near the crops' roots. The same principle of heat exchangers is also used in fishing farms. It worth noting that irrigation of greenhouse may decrease the temperature to an unwanted level during the heating period time. To overcome that, the rate of the irrigation flow must be considered in a given greenhouse area during design. With that, overall heat loss in a given greenhouse achieves optimum efficiency from the implemented geothermal system plan. The crop requires a certain desired temperature for growth; this internal temperature must be maintained at all times. The minimum reference temperature must be set to a design value to verify all appropriate conditions for crop growth. The greenhouse is a convenient environment for crop growth all over the year and it is not restricted to seasonal output. This increases prices because such crops are not available during certain times of the year. Thus, using greenhouses is a suitable method to conserve crops by controlling growth conditions like temperature, light, and humidity. It is also helpful economically , the study cocluded that The CO2 emission for the studied scenario of a GSHP unit for heating is 149 or 65 g CO2/kWh, respectively depending on the considered electrical energy mix compared to 229 g CO2/kWh for a conventional heating mix, indicating that at least 35% of additional CO2 emissions could be avoided with the application of GSHP systems. **[13]**.

During winter daytime, the temperature is reasonable, and the humidity is relatively lower than nighttime because it is sunny and dry. That is why humidity control is not an issue at this period in contrast to lower temperature conditions at night. While this is acceptable for ventilation purposes, opening some side walls slightly during the day and closing them at sunset to prevent cold air from entering. The air in the greenhouse has similar humidity as in the outer ambient air, even after closing all outside air access. However, the air is not inside and since it is dry, it took a long time for water-vapor to condense at high levels. This means ventilation is required the next morning. At night low-temperature levels become a challenge that must be overcome by adequate control. This applies to all kinds of crops. One way to save the crops inside the greenhouse during challenging temperatures at night is by burning some of the fossil fuel. This is not a feasible option at this stage as it is costly despite its effectiveness in preventing the total loss of plants. Furthermore, the affected region in the greenhouse will not have fully grown crops **[14]**. This effect decreases production and quality, especially during winter as prices are often high. In passive solar greenhouse applications, the temperature tends to decrease at night.

Geothermal energy has been used experimentally to provide required heating for the greenhouse by putting polyethylene tubes that contain a heat storage medium such as water. This medium comes from geothermal origins, in addition to the roof from thermal curtains, the study conclude that experimental results obtained are satisfying to develop this technique in the near future for supply population in these regions where the geothermal water, clean and free energy, exists on abundance. **[15]**. Using passive solar requires more area than the water volume per square meter provided to support all crops while water circulates to maintain the desired temperature. This has already been implemented in different applications as a substitute for solar radiation. Geothermal energy is beneficial for greenhouses because it provides heat to the floor and crops' roots. On the other hand, solar radiation only affects the air in the greenhouse. That is good for crops but is ineffective during winter as the floor temperature is inadequate. The floor emits radiation and covers the surrounding air, conditioning temperature **[16]**. Mahmoud et al **[17]** performed an numerical study on enhancement of earth-to-air heat exchanger heat transfer using porous media, the study conclude that for laminar flow an enhancement in the bulk temperature difference across the EAHE of up to 25 % can be achieved using only 10 mm thickness of carbon foam V-shaped insert. Results also show that changing the apex angle of the V-shaped insert can significantly reduce the pressure drop across the porous insert. A volume saving of up to 40 % can be obtained in the EAHE by using the V-shaped configurations. The Solar Energy Institute, Ege University – Turkey **[18]**, conducted a study on the use of geothermal energy in a greenhouse application. The study highlights the exergetic performance characteristics of an underground air tunnel that controls the temperature in greenhouse applications using a 47 m long, 56 cm nominal diameter galvanized steel pipe. The system coefficient of performances COP changed with the soil's wetness, the study conclude that UAT was able to provide 60.8 percent of the design heating load cold winter days. In spite of difficulties primarily encountered in coupling geothermal energy with conventional space heating and cooling equipment, UATs seem to be an exciting alternative.

Many other studies examined the performance of using a solar chimney for natural ventilation. For 25 years, many countries used geothermal energy to provide conditioned air for greenhouse application and provide a stable source of energy throughout the year, noting that geothermal energy is not affected by outside weather temperature. In this study will perform analysis on the thermal performance of hybrid geothermal-solar energy system to control the air temperature in a closed environment and conduct an experiment to obtain relationships between the controlling parameters and recommend the dimensionless form relationship that achieves the best thermal performance.

2. Numerical analysis

The first step is to choose a depth for the application. There was an attempt to establish a depth of 12 meters in the analysis. However, different researches and experimental studies in Turkey **[6]** and Egypt in which the study showed that using of an ETAHE system for heating greenhouse was more efficient and low cost compared to using it for cooling in all cases of pipe diameters. **[19]** used different depths that start from 1 to 4 meters. Therefore, it is recommended to implement a 4-meter depth in the current study, where the temperature is constant at 20 ^{o}C.

Furthermore, after literature review, a recommended solar chimney angle and dimensions were obtained. Afterwards, an attempt to examine different designs that accommodate for such conditions and to predict positive and negative effects.

2.1 Design

Four designs were investigated in this study. The first design was an open system. Fresh air entered directly from outside of the system and went through the underground pipe. Then, it passed through the room and was released through the solar chimney, as shown in **Fig 3.** The second design was a closed system and the solar chimney system was isolated from it. Hot air is released through the chimney using valves as shown in **Fig 4.** The third design is a completely closed system and allows for complete control using valves as shown in **Fig 5.** The fourth design was ideal as it is entirely closed, including the chimney, and there is a bypass for the solar chimney to prevent air from passing through it is not required. This is implemented by using valves. To add, there is a fresh air inlet gate that can be opened to let fresh air enter due to pressure difference, resulting in a vacuum effect, as shown in **Fig 6.** The pipe diameters and lengths vary to determine its effects on reaching the target temperature.

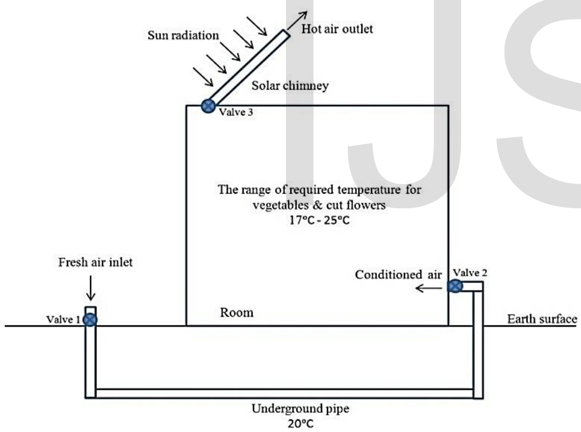

Fig.3. Diagram of first system design

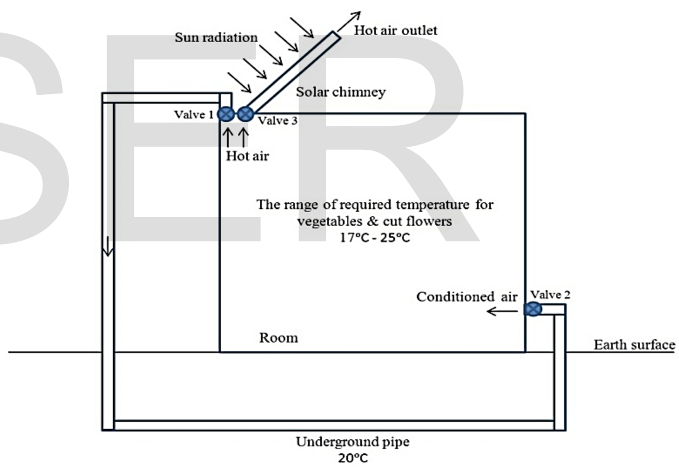

Fig.4. Diagram of second system design

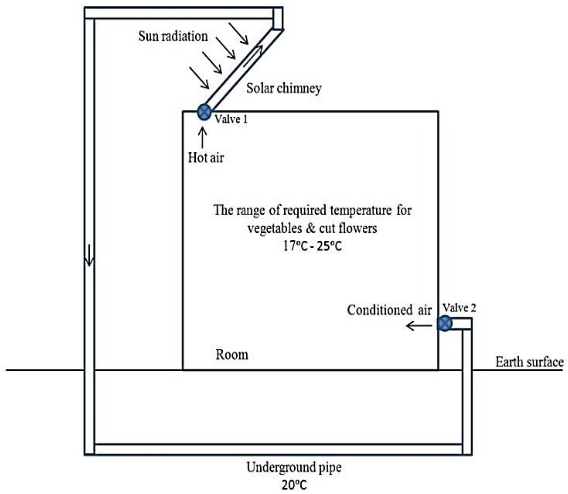

Fig.5. Diagram of third system design

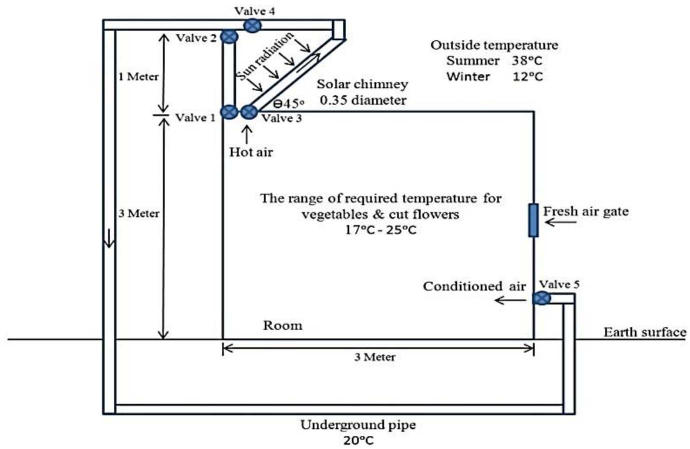

Fig.6. Diagram of fourth system design

Summer operation

- Close valve 1 + valve 2 + valve 3 + valve 4 + valve 5: The flow will be trapped underground till the required temperature is obtained.
- Upon reaching the required temperature, valve 1 + valve 2 + valve 5 will be opened, while valve 3 + valve 4 will remain closed to keep the chimney isolated. The hot air passes through valve 1 and valve 2 pipe (upwards), allowing cold air to pass inside the room through valve 5 due to air density difference and the negative pressure generated, allowing the flow of air in such manner.

Winter operation

- Close valve 1 + valve 2 + valve 5 and keep valve 3 + valve 4 opened: The chimney will increase the temperature inside the pipe and reduce the time required to reach the target temperature.
- Open valve 5, keep valve 3 + valve 4 opened, and keep valve 1 + valve 2 closed: The flow becomes reasonable because of the chimney's effect and the air's temperature will remain high for a long time before repeating the cycle. The fresh air gate remains closed unless O_2, CO, CO_2 & N percentages change inside the room. In that case, it is opened temporarily during step B until it reverts to the required quality in the room. Fresh air enters via pressure difference in the same manner as the one implemented with valve 5.

Numerical analysis is used to design the entire system. There were some problems during this step as the solar chimney interfered with the summer outlet pipe. As such, some modifications were made. The boundary condition was set as shown in **Table 2.** The numerical model, including the chimney and bypass connection that contains the blower, is shown in **Fig.7.** The numerical model consists of a room with dimensions of L X W x H = 3 X 3 X 3 m, and surface area of 54 m^2. The solar chimney is 1 m high ,and the underground connection pipes are two pipes of 3.575 m length each. Above the ground surface, the connection pipes are 7.459 m long.

Table 2 Boundary and initial conditions (BC & IC)

	Fluid flow	Thermal
Room (IC)	Wall (no-slip)	Isothermal t=285 k (12 C)
Connection pipe (atmospheric) (BC)	Wall (no-slip)	Adiabatic (Q=0)
Connection pipe (underground) (BC)	Wall (no-slip)	Adiabatic (Q=0)
Underground pipe (soil surface) (BC)	Wall (no-slip)	Isothermal t=293 k (20 C)
Chimney (BC)	Wall (no-slip)	Solar Heat flux (400 watt/m2)

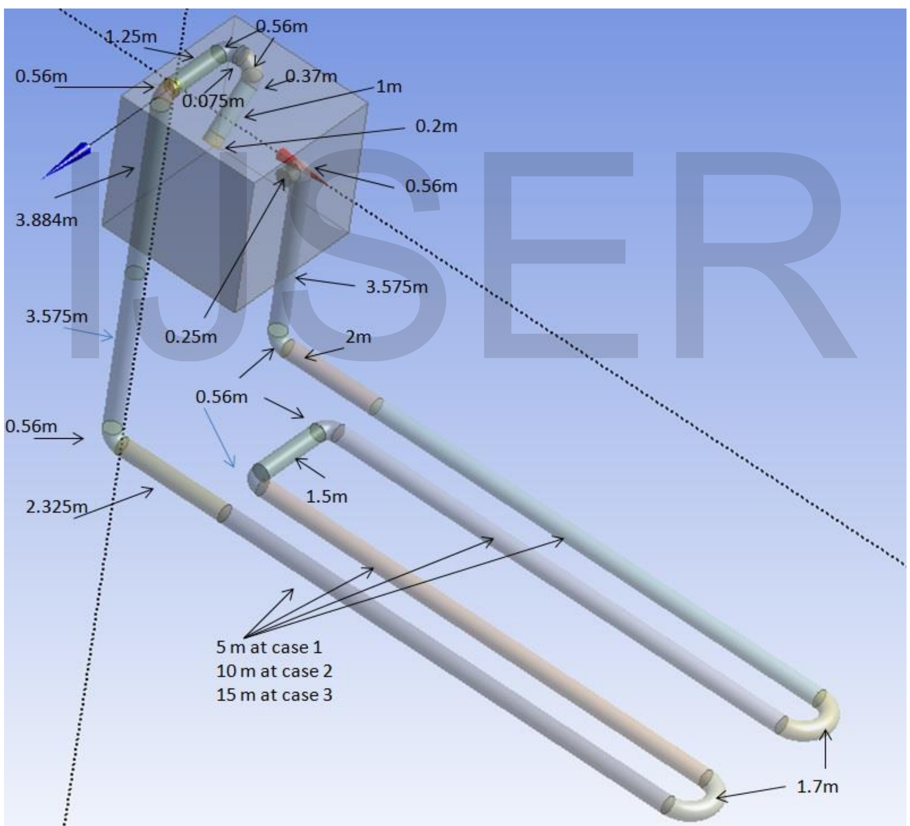

Fig.7. The proposed system design

In this study, two computational models were proposed; the first model (model A) does not include the solar chimney to determine the temperature difference the system exhibited without a chimney in summer conditions. In contrast, the second model (model B) includes the chimney but does not include an extra section to examine the effect of the chimney during winter conditions.

2.2 Discretization

Different meshes were generated in this numerical analysis. The model uses 157245 hexahedra elements with max skewness of 3.28115 , aspect ratio is 128.081 and minimum volume equal to 2.7286e-09 m^3 , the convergence criteria was achieved when the relative error of the temperature change is less than 0.001, a fresh air inlet was added to each case separately to see what would happen, resulting in a system with a chimney case as shown in **Fig 8.**

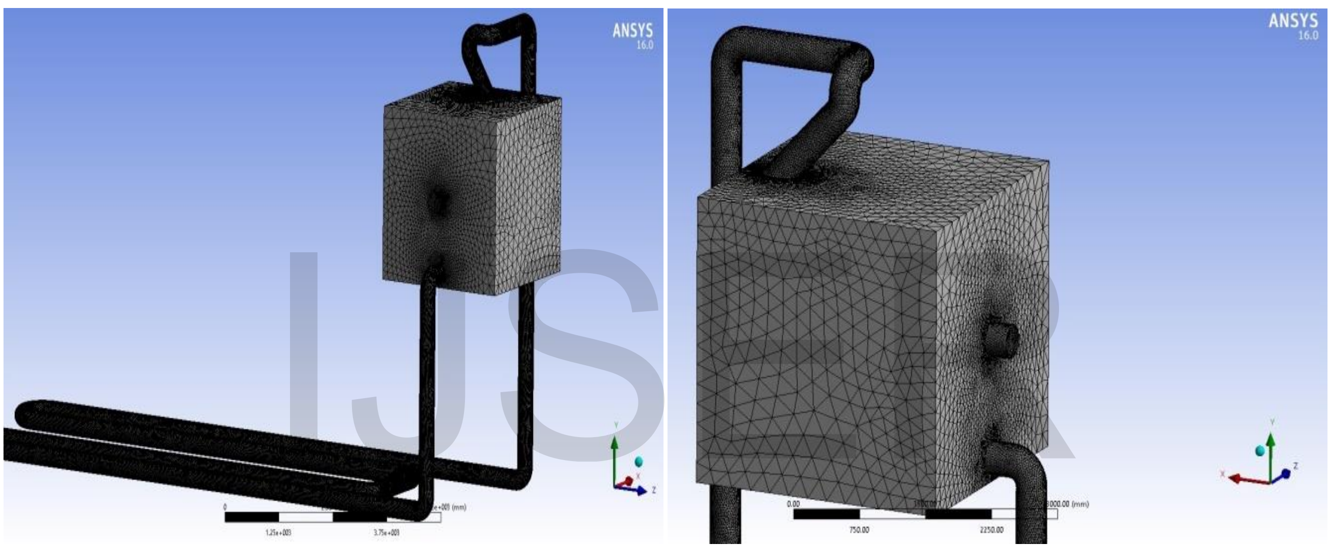

Fig.8. Fresh air inlet in winter system mesh design

In some cases, forced flow is required therefore, a small AC 55 watts fan, 20 cm diameter was added to the system to direct the flow to the proper path. The fan can be also controlled to stop the flow for some time or change its speed for some time to attain the required temperatures. The fan is an easy method for controlling the system flow rate and temperature. It was required to make the system mesh smaller for more accurate results. The fan positioning is shown in **Fig.9.**

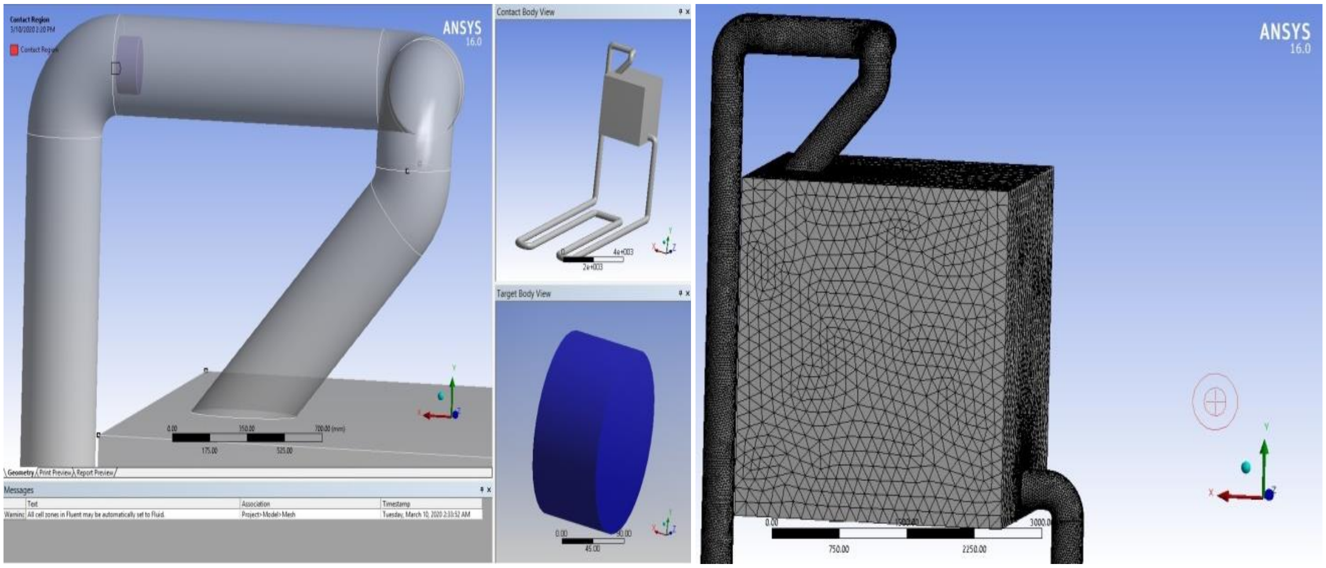

Fig.9. Fan location in the system mesh design

3. Experimental work

An experiment was conducted for validation of numerical results, in Damanhur , Egypt, with longitude and latitude of 31°01'50.7'' N and 30°26'49.5'' E respectively. as shown in **Fig 10.**

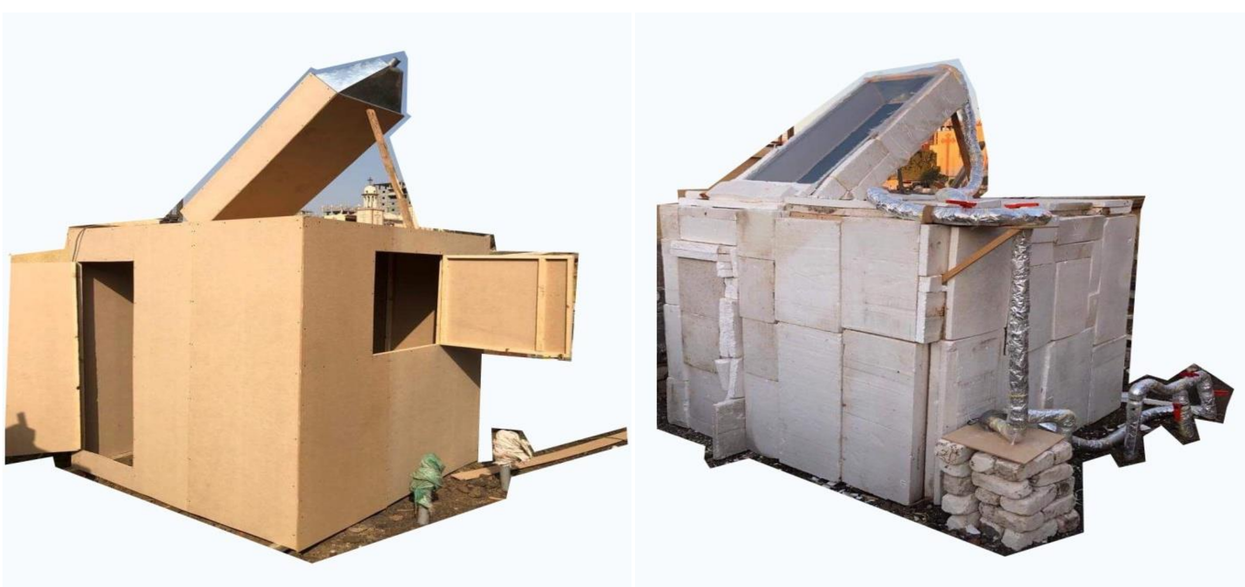

Fig 10. Experimental setup.

The solar chimney consists of 0.3 m width air gap thickness , front glass of 5 mm in thickness supported by of 10 mm wood hood was placed with an angle of 45^{o}, 1.6 m long 0.7 m. To add, its base painted black to help performance. the sides of the chimney are insulated by a 0.6 m Styrofoam material 0.03 W/ m.K, characterized by low thermal conductivity, and the bottom of the chimney insulated by glass wool of 25 mm thickness, density 16 kg/m^3 & 0.04 W/ m.K, with low thermal conductivity. It is attached to the cubic room with the dimensions 2 W x 2 L x 2 H meters manufactured by 10 mm thickness wood and covered by Styrofoam 12 cm thickness to act as insulation.

Geothermal 5 meters PVC tubes 2 inches diameter 5.3 mm thickness was buried at 2 m depth as shown in **Fig 11.** It is connected 0.2 m above ground to the room. The other side of the pipe is connected in 2 ways; the first is attached to the chimney and the second is a bypass for the chimney, where the pipe connects to the room ceiling Two valves are used to control the chimney connection pipeline and its bypass pipeline. All earth outside pipeline connections is insulated by glass wool. The room has a door of 172 cm height and 59 cm width. It is usually closed and is only used just used to shut off the system before checking room internal sensors, closing/opening chimney inlet, or closing/opening bypass line inlet. A window of 0.8 m height x 0.8 m width was in the same wall containing air inlet pipe. the window is 0.2 m from the ceiling and is located in the middle of the wall. It is usually closed, which allows the system to act as a closed-loop. However, some experiments had an open window for ventilation and adjusting the air quality level inside the room while running the close loop system. "Ebmpapst" model number G2S097AA03.03 55 watts 0.3 amperes 220 volts 2480 rpm air blower is attached to the connection point between chimney outlet and its bypass line. The air temperature inside the room was measured at the middle of the room.

Fig 11. Installing geothermal pipe

4. Validation

In this study, the process of conditioning air using hybrid geothermal-solar system will be investigated. The thermal performance of hybrid geothermal-solar energy system to control the air temperature in a closed environment will be analyzed. This analysis includes changing: the pipe length, diameter, depth, air flow rate, and height and angle of the solar chimney. The experimental and numerical work aim to obtain relationships between the parameters under study. Results will then be presented in a recommend dimensionless form to obtain the best thermal performance. Finally, validation of numerical results with experimental data. Different pipe geometries were used in the numerical and experimental studies as shown in **Tables (3, and 4)**, which show the proposed pipe diameters and lengths under study. A range of different diameters and lengths varies from 0.17 m to 0.65 m , and from 47 m to 87 m respectively were used to carry out the study.

Table 3 Parameters of numircal analysis

CFD RESULTS	DIAMETER D, LENGTH L								
	D 0.17 , L 47.047	D 0.17 , L 64.074	D 0.17 , L 87.074	D 0.35 , L 47.047	D 0.35 , L 64.074	D 0.35 , L 87.074	D 0.65 , L 47.047	D 0.65 , L 64.074	D 0.65 , L 87.074
Reynolds Number Winter (Rn)	4673	3865	4140	5975	5789	5690	10058	11042	11036
Reynolds Number Summer (Rn)				7660	7097	6314	11870	13074	8552
Relative Roughness	0.000882	0.000882	0.000882	0.000429	0.000429	0.000429	0.000231	0.000231	0.000231
Absolute Roughness ε (0.15 mm) / Velocity	0.000343	0.000415	0.000387	0.000553	0.000570	0.000580	0.000610	0.000555	0.000556
Nusselt number (Nu)	22.44	22.44	22.44	42	42	42	75.4	75.4	75.4
L/D	277	395	512	135	192	249	72	103	134

Table 4 Experimental PVC Pipe diameter and length size study

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EXPERIMENTAL SIZE STUDY USING PVC		Pipe Diameter (INCH)									
		0.25	0.5	0.75	1	1.25	1.5	1.75	2	2.25	
		Pipe Diameter (METER)									
		0.0064	0.0127	0.01905	0.0254	0.03175	0.0381	0.04445	0.0508	0.05715	
Total Pipe Length (METER)	1	157	79	52	39	31	26	22	20	17	L/D
	2	315	157	105	79	63	52	45	39	35	
	3	472	236	157	118	94	79	67	59	52	
	4	630	315	210	157	126	105	90	79	70	
	5	787	394	262	197	157	131	112	98	87	
	6	945	472	315	236	189	157	135	118	105	
	7	1102	551	367	276	220	184	157	138	122	
	8	1260	630	420	315	252	210	180	157	140	
	9	1417	709	472	354	283	236	202	177	157	
	10	1575	787	525	394	315	262	225	197	175	
	11	1732	866	577	433	346	289	247	217	192	
	12	1890	945	630	472	378	315	270	236	210	
	13	2047	1024	682	512	409.4	341	292	256	227	
	14	2205	1102	735	551	441	367	315	276	245	

To validate the numerical model, a dimensionless temperature Θ was defined, that is (Temperature of outside weather - Minimum temperature of the room) / (Maximum temperature of the room - Minimum temperature of the room). The dimensionless temperature Θ was plotted versus time as shown in **Figure (12)**

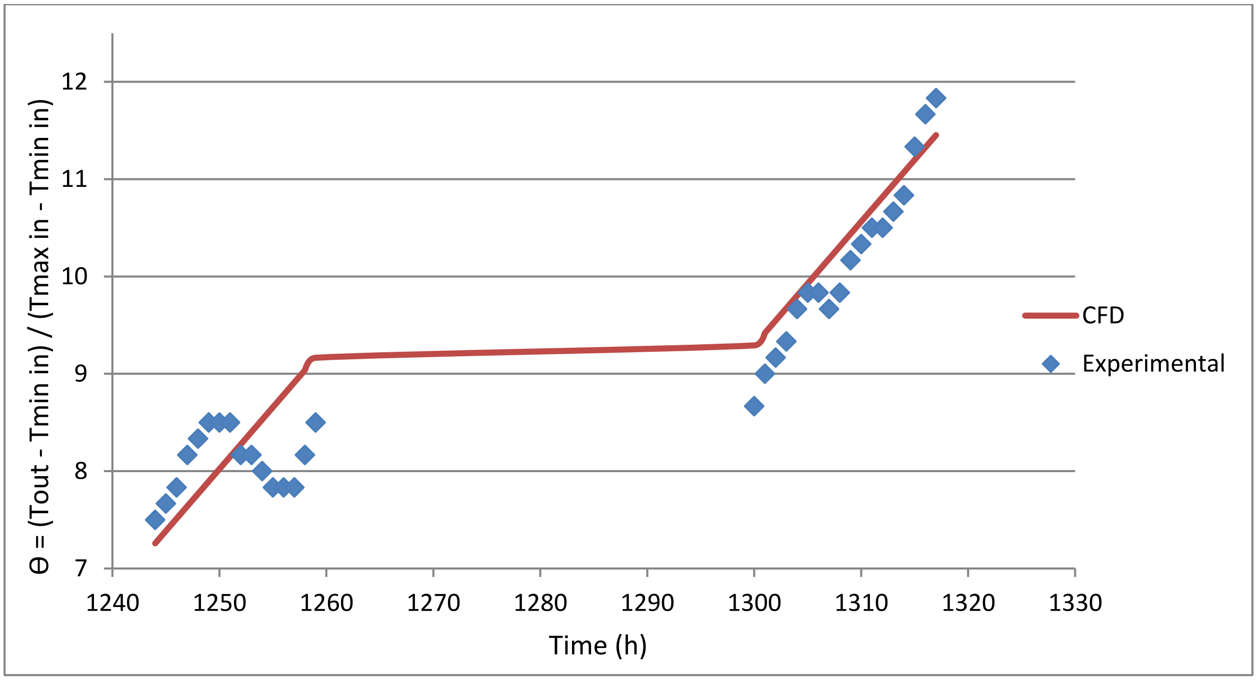

Fig 12. Validation pipe size 31 m length & 17 cm diameter.

5. Results & Discussion:

The application of a solar chimney into geothermal application improves the total system performance. This is because the chimney improves air circulation and the reduces the time required to heat up the air. Upon examining the relations between all system parameters, including air flow rate and time required for air conditioning, more control is given to the system, the boundaries of the parameter during design become clear and the system operational stage reaches the target temperature in a short time. The air temperature inside the room was measured as an average.

The mass flow rate in the chimney for a room with two openings and a uniform room air temperature is calculated as follows [19]:

$$m = \frac{C_d \rho_{f1} A_O}{\sqrt{1 - A_r^2}} \sqrt{\frac{2gL\, sin\, (T_f - T_r)}{T_r}}$$

Where

A_r = Ao/Ai, Ao, and Ai were outlet and inlet areas

C_d Coefficient of discharge of air channel inlet

T_f mean temperature of the air in the channel

T_r room temperature

ρ_f flow density

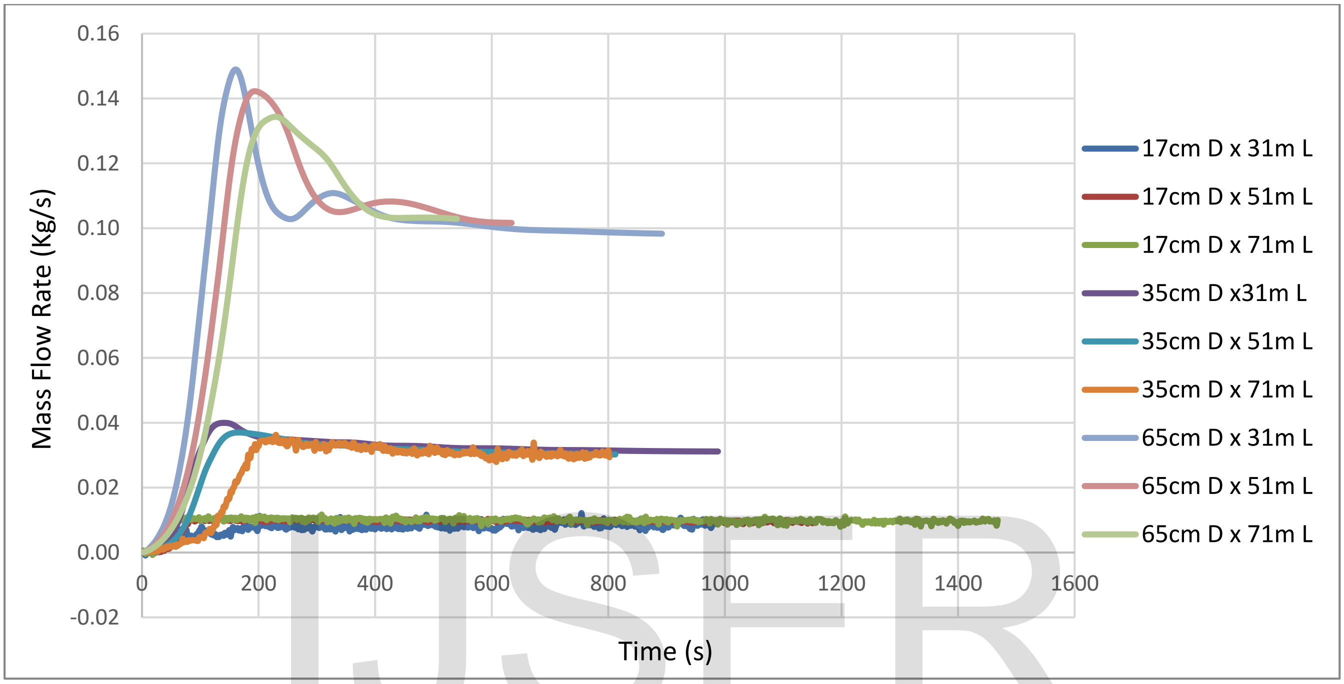

Fig.13. Mass flow rate vs time in winter operating conditions

Figure (13) shows using a 31-meter length pipe that has a 17 cm diameter, the time required to reach 0.01 kg/sec flow rate is 200 seconds. The maximum flow rate is 0.012 kg/sec, achieved after 754 seconds. Using a 31-meter length pipe with a 35 cm diameter, the flow rate reaches 0.04 kg/sec in 140 seconds. The flow rate decreases to 0.031 kg/sec and becomes steady in 634 seconds. If a 31-meter length pipe with a 65 cm diameter is used, the curve shows that the time required for the flow rate to reach 0.149 kg/sec is 160 seconds. Then, it decreases to 0.1 kg/sec in 576 seconds and becomes steady. A 51-meter long, 17 cm diameter pipe reveals that the time required for the flow rate to reach 0.01 kg/sec is 83 seconds before stabilizing. In the case of a 51-meter length pipe with a 35 cm diameter, the time required for the flow rate to reach 0.037 kg/sec is 166 seconds. Afterward, it decreases to 0.03 kg/sec and becomes steady in 592 seconds. Using a 51-meter length pipe with a 65 cm diameter, the time required for the flow rate to reach 0.142 kg/sec is 194 seconds. Then, it decreases to 0.1 kg/sec and it becomes steady in 296 seconds. Using a 71-meter length pipe with 17 cm diameter requires the flow rate to reach 0.01 kg/sec 68 seconds and then it becomes steady. If a 71-meter length pipe with a 35 cm diameter is used, the time required for the flow rate to reach 0.036 kg/sec is 230 seconds. it decreases to 0.03 after 200 seconds and becomes steady. Using a 71-meter length pipe with a 65 cm diameter, the flow rate reaches 0.134 kg/sec in 222 seconds. Then, it decreases to 0.1 after 140 seconds and becomes steady.

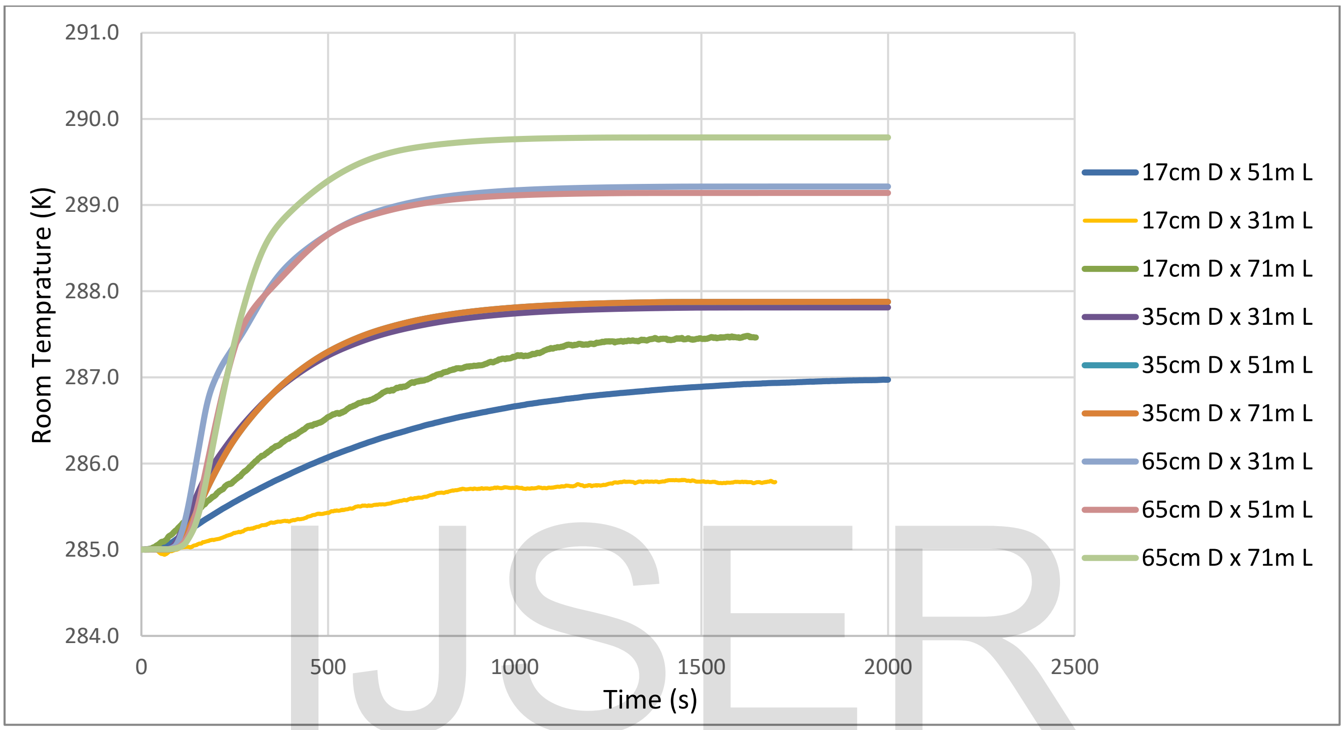

Fig. 14. Room temperature vs time in winter operating conditions

Figure (14) shows that using a 31-meter length pipe with a 17 cm diameter, the room temperature reaches a steady state at 1400 seconds. By increasing the pipe diameter to 35 cm with the same pipe length, the temperature increases by 1 kelvin every 460 seconds, and then the steady-state temperature is reached after 1000 seconds. Further increase of the pipe diameter to 65 cm with the same pipe length leads to an increase of the temperature rate to 1 kelvin in 145 seconds, and the maximum temperature is achieved at 1000 seconds. Using a 51-meter length pipe with a 17 cm diameter, the room temperature reaches a steady state at 1500 seconds. By increasing the pipe diameter to 35 cm with the same pipe length, the temperature increases 1 kelvin in 460 seconds and then the steady-state temperature is reached after 900 seconds. Further increase of the pipe diameter to 65 cm with the same pipe length leads to an increase of the temperature rate to 1 kelvin in 148 seconds, and the maximum temperature is achieved at 1000 seconds. Using a 71-meter length pipe with a 17 cm diameter, the room temperature reaches a steady state at 700 seconds. By increasing the pipe diameter to 35 cm with the same pipe length, the temperature increases by 1 kelvin every 216 seconds, and then the steady-state temperature is reached after 1000 seconds. Further increase of the pipe diameter to 65 cm with the same pipe length leads to an increase of the temperature rate to 1 kelvin in 184 seconds and the maximum temperature is achieved at 600 seconds.

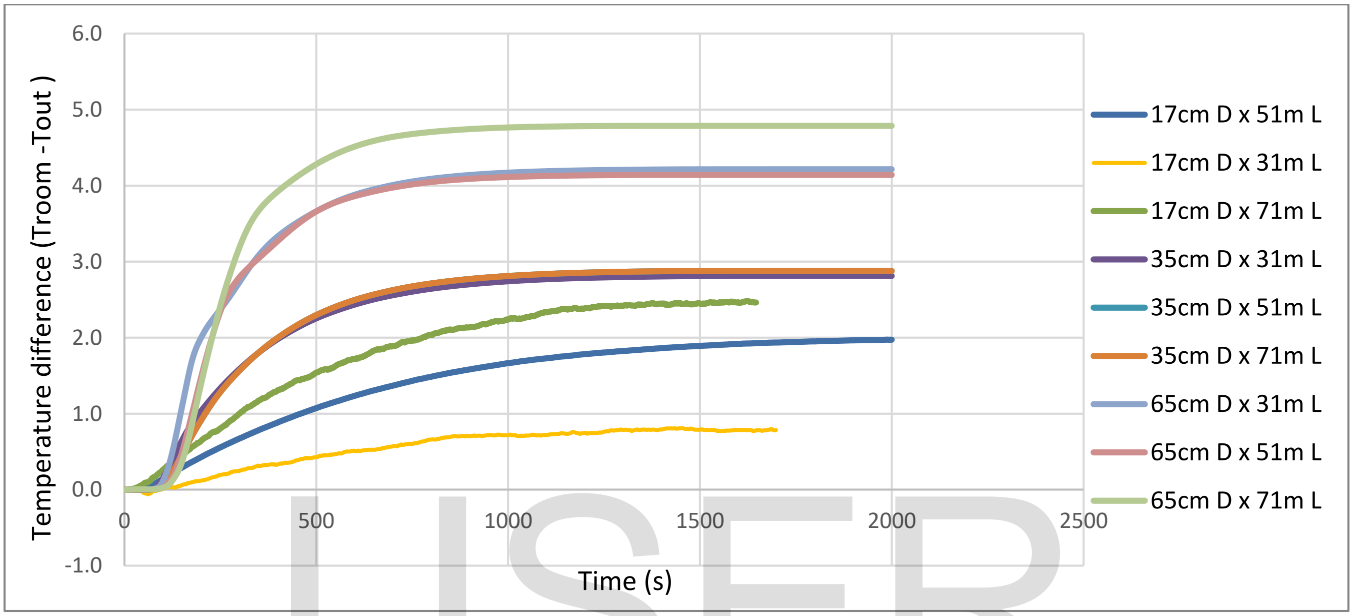

Fig.15. Temperature difference vs time in winter operating conditions

Figure (15) shows that the maximum temperature difference happens at 65 cm diameter with 71 m length 65 cm and diameter with 31 m & 51 m length. The minimum temperature difference at 17 cm diameter and 31 m length is less than 17 cm diameter and 51 m length. **Fig (16)** elaborates the relation between mass flow rate and temperature difference.

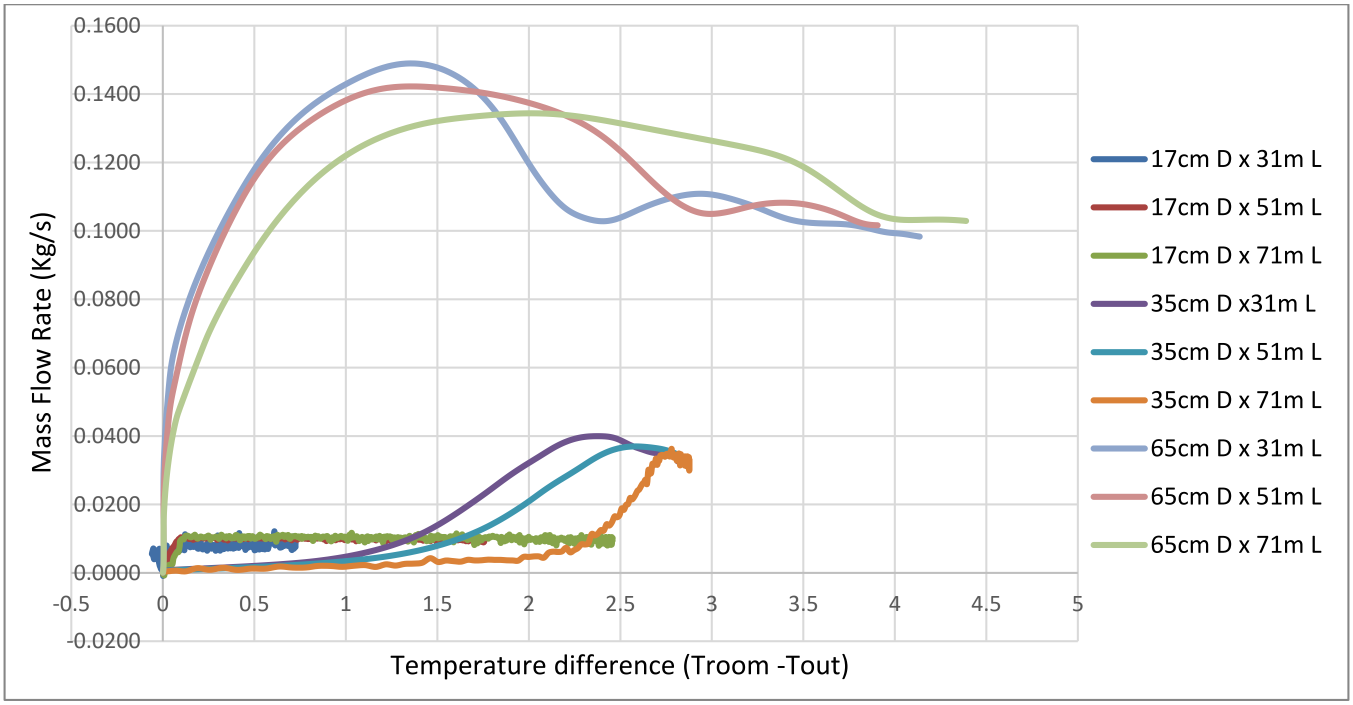

Fig.16. Mass floe rate vs temperature difference in winter operating condition

Conclusion

A closed-loop geothermal air pipe supported by a solar chimney and air blower is studied and used in numerical analysis for nine different pipes with different diameters and lengths. The study is verified with experimental work, solar chimney angle, room size, and PVC pipe diameter. The depth of geothermal pipes was selected based on the recommendation from previous studies. CFD studies show that some results are close and the smallest pipe achieves similar results to bigger ones. However, it reduces the initial cost. Therefore, the 31 m long with 65 cm diameter pipe is a good choice for maximum flow rate. This is validated experimentally with a pipe of similar geometry. It achieves the same temperature difference for cooling during hot weather/summer and dimensionless ϴ is corresponding in both cases. During winter conditions the maximum temperature difference achieved is 4.8 while in summer conditions is 5.7.

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