THESIS TITLE

EAHE-Solar Chimney Coupled Passive Cooling System and the Simulation

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This is to certify that the work presented in this thesis is an outcome of experiment and research carried out by the authors under the supervision of Md.Mustafizur Rahman.

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List of Acronyms

Roman letter symbols

cp	constant-pressure specific heat of air
h	enthalpy, kJ/kg
m	mass flow rate, kg/s
Q	rate of heat transfer, kW
T	temperature,
V	volume flow rate of air flow

Subscripts

air	air
cooling	cooling
l	latent
s	sensible
system	system
t	total
total	total
vap	vaporization
w	water
EAHE	earth-to-air heat exchanger
HR	humidity ratio
OA	outdoor air
OAT	outdoor air temperature
RA	room air
RAT	room air temperature
SA	supply air
SAT	supply air temperature

UUS	undisturbed underground soil

Greek letters

u	humidity ratio, kg/kg
r	specific density, kg/m

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T.M. ABIR AHSAN
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Abstract

In the 21st century the talk of the time has been proper use of renewable energy sources due to the continuous depletion of non-renewable energy sources and global warming as a result of combustion of fossil fuels. The energy situation in the 3rd world countries is even worse. The continuous industrial development in the 1st world countries is hugely responsible for global temperature increase and greenhouse gas (GHG) emissions which badly affect the countries like Bangladesh. As of April 2016, the electricity generation capacity of Bangladesh was 12,399 MW to which only 60% of the total population have access to. The shortage of electricity during the summer season makes life very difficult. Cooling of buildings requires a large quantity of energy in the summer. An alternative cooling system can reduce the dependency on electricity. This paper specially deals with a passive cooling system that reduces pressure on the electricity supply and focuses on renewable energy sources. Here a different process engineering has been discussed which incorporates Earth-to-Air Heat Exchangers with solar collector enhanced solar chimney system. In this study natural ventilation of buildings, using solar chimney system is reviewed extensively. Experimentally it has already been observed that sufficient temperature drop takes place 2-3 m within the undisturbed ground, which can work as a heat sink for ambient air if passed through and can lead to attaining comfort zone at a confined location. During peak hours of summer this kind of system may work as a very efficient cooling system and reduces extra load on electricity supply

Introduction

In this 21st century, one of the main goal is the proper use of renewable energy sources due to the continuous exhaustion of non-renewable energy sources which is soon to be coming to a cease [1]. The condition is even worse when it comes to the case of 3rd world countries. The continuous industrial development in the 1st world countries are adding global temperature increase and greenhouse issues which work as an insult to an injury situation on countries like Bangladesh. GHG emissions have been increased substantially due to increased fossil fuel consumption [2-3]. Only 60% of the population has access to grid electricity [4] in Bangladesh. So it is difficult in summer to lead the normal life as people do not even have access to electricity in many cases. Moreover, cooling of buildings need more energy, which can hardly be afforded. These situations lead to the alternative approach of cooling buildings using renewable energy sources. Different researches are being performed to improve the cooling capacity in building sectors using renewable energy sources. Ground source heat pumps (GSHPs), earth-to-air heat exchangers (EAHEs) and many more techniques are using renewable energy sources with high heat capacity and thermal inertia underground. This paper reviews a different process engineering which incorporates Earth-to-Air Heat Exchangers with solar collector enhanced solar chimney system. Mathematical modeling was the main focus for researches on EAHE. EAHE was treated and simulated as a cylindrical 2D heat transfer problem in one model, then this had to work with latent heat transfer instead of only sensible ones, then adiabatic/isothermal boundary conditions with harmonic temperature signal has been simulated also and it is shown that at different thickness, the soil layer could induce either an amplitude-dampening or phase-shifting regimes [5]. Various experiments have been conducted to check the effects of locations, material types and sizes on the performance of the EAHE systems [6-9]. Solar chimney is another way which can serve this purpose utilizing solar energy. Solar chimney is a capturing surface and thus air is heated up by solar energy in chimney and due to stack pressure build up the air flows throughout the chimney. It gives a driving force for sucking outside air to the cooling pipe. CFD analysis is used in researches for tracing mass and airflow rate [5]. Chimney gap, inclination, chimney height, solar collector surface area are some other parameters are taken into account for analysis in the researches [10-12]. This review paper actually talks about the combined experiments using EAHE with a solar chimney and collector to achieve a greater success on cooling as well as ventilation. The solar and geothermal energy sources can make the whole system a unique one.

Experimental Setup

EAHE is horizontally buried pipe under certain depth of soil, which can be made of plastic, concrete, ceramic or metallic pipe [5]. One end of the pipe is exposed to the outside atmosphere from where the outside air will be sucked in where a fan or blower can be used. The ground works as a heat sink here. The average temperature of undisturbed ground under certain depth shows much lower readings than that of the ambient air in the summer season [5]. Temperature readings were taken in three different depths and the effect was justified [5]. Temperature readings under 1m, 2m, and 3m depth measured by J type thermocouples showed that temperature reduces with the depth but up to a certain point. At the depth of 3m satisfactory temperature drop was observed [5]. About 8°C fluctuation was achieved in the highest depth (3m) of the experiment. Depth of the soil, thermal diffusivity, surface temperature are some of the variables that affect the temperature readings. Thus, the incoming air through the EAHE pipe exchanges heat and gets cooled down according to the thermal nature. The other end of the pipe is driven inside the room of buildings by which cooled air will enter the room and decrease the temperature. Sand can be used for good thermal connection and EAHE can have both common or individual inlet and outlets. Small tilting of the pipes and small holes in lower parts can solve for condensation and water collection problem, respectively. Figure 1 shows the experimental setup used in the study by Li et al. [5].

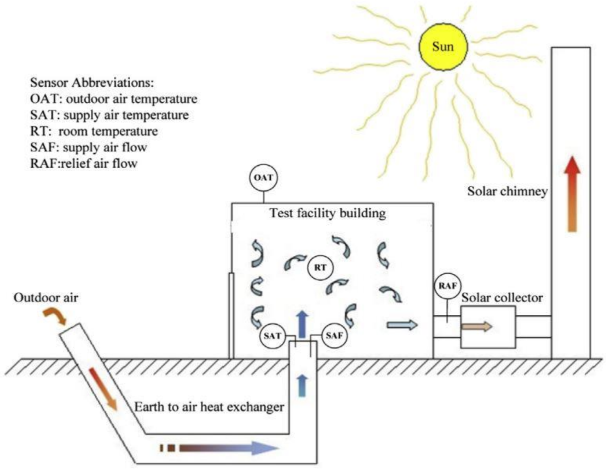


Figure 1: Schematic diagram of a coupled system with EAHE and solar chimney

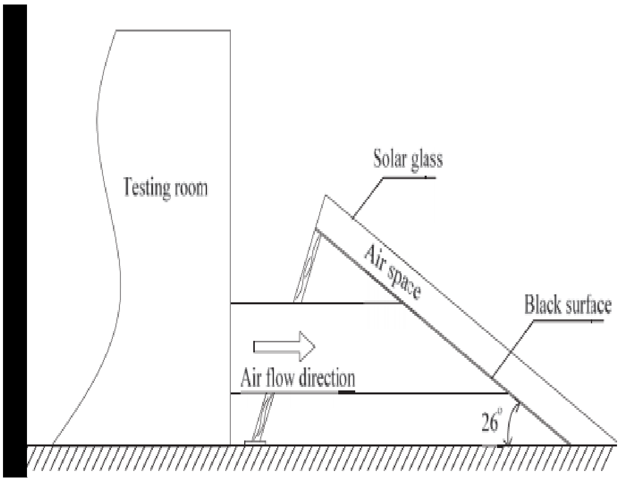


Figure 2: A cross section view of the solar collector and the Solar Energy Research Test Facility-solar collector connection pipe [5]

A solar chimney through a solar collector is integrated in the system (see Figure 1). Solar chimney is different from the solar updraft tower (SUT) which is a renewable energy power plant for generating electricity from low temperature solar heat. Sunshine heats the air beneath a very wide greenhouse-like roofed collector structure surrounding the central base of a very tall chimney tower. The resulting convection causes a hot air updraft in the tower by the chimney effect. This airflow drives wind turbines placed in the chimney updraft or around the chimney base to produce electricity. But here solar chimney works in a different way. The collector is inclined at some angle so that it can receive the maximum available solar energy. The exhaust air from the test facility room flows into the solar collector, which is in turn heated by the trapped solar radiation. The heated air has lower density and so has a tendency to rise upwards. A convection current is set up due to density differences and the air flows into a solar chimney and move up out of the chimney. The drop in density provides a buoyancy force to the air within the solar chimney to rise and consequently be expelled out of the chimney to the exterior.

The system being connected altogether tightly, the outward flow of the chimney air creates suction on the side of the EAHE inlet and the ambient air enters the horizontally buried pipes. Heat exchange occurs in the pipe between the underground soil and the entered air and thus the air is cooled down. Thus, a fresh and cool air goes into the test room and reduces the room temperature. All these components altogether the system forms a quite feasible and efficient natural ventilation that passively cooled buildings can employ.

Some parameters to be considered are - depth of pipes (2m to 3m), length (>20m) and diameter of pipes (0.2m to 0.3m), air speed inside pipes (6 to 10 m/s), distance between pipes (2m) for heat dissipation, control system, etc. A simple control system can be introduced for the desired performances. Two main configurations of the EAHE can be used in this system. They are “Open Loop” and “Closed Loop” [13]. In the open loop process, the atmospheric air will enter the EAHE pipe inlet and after the heat transfer the cooled down air will be directed towards the testing room. On the other hand, in closed loop the inlet and outlet both are inside the building. The warm air of the room after circulating will be directed to the EAHE pipes. Then there will be heat transfer inside the EAHE under the soil and then the further cooled air will be directed to the room to make it cooler. It is the closed loop system [13]

Figure 3: Experimental Setup of the Passive Cooling System

Integration of Solar Chimney Using EAHE System Ensuring Ventilation

The main goal of designing the EAHE system has been to evaluate thermal performance of passive, naturally driven, coupled system, through assessing the maximum cooling capacity, airflow rate that it can ensure for the testing facility building.in the experiment conducted in the facility building the damper was set to 100% open position. Main measurements that were recorded for the purpose of analyzing the cooling capacity of the naturally driven coupled system are time and date, indoor, outdoor and supply air relative humidity (%), supply air flow rate, average indoor and supply air temperature ,solar collector air flow rate and the system thermal performance [5].

Due to the internal gains and heat transmission through the wall and roof, daytime ventilation is necessary to develop the indoor air quality and to remove heat. Outdoor air can be induced into buildings by solar chimneys. However, if the outdoor air temperature exceeds the thermal comfort limit, it is necessary to precool it. The precooling of external air before entering the buildings may be attained by natural means, such as evaporative cooling ground cooling, etc. Macias et al. [14] reported a passive cooling system, which was developed as a part of design work for the project of a low cost residential building, and it incorporated a solar chimney and precooled the air by using the sanitary area of the building. The natural ventilation was enhanced with the help of the solar chimney and fresh air was cooled down by circulation within the sanitary area. It was found that the implementation of the passive cooling strategy allowed ensuring thermal comfort through low conventional energy consumption. Maerefat and Haghighi [15] offered a passive solar system containing of solar chimneys and earth to air heat exchangers. The proposed solar system consisted of two parts: the solar chimney, and the earth to air heat exchanger. The solar chimney included a glass surface oriented to the south and an absorber wall that worked as a capturing surface. The air was heated up in the solar chimney by the solar energy, and flowed upward because of the stack effect. It caused driving force that sucked the outside air through the cooling pipe. The earth to air heat exchanger was composed of horizontal long pipes that were buried under the naked surface at the specific depth. The pipes were spread under the ground in a parallel manner.

Calderaro and Agnoli [16] suggested setting up solar chimneys close to high thermic storage structures in an energetic retrofit. By the integration of the indirect evaporation system, the simulation results showed that such a collector storage system was capable of softening summer temperatures. In winter, it allowed the contemporary working of thermal storage and heat transferring toward the bordered setting, through natural thermic circulation circuits. The energetic consumptions and the environmental pollution could thus be reduced.

Maerefat and Haghighi [15] put forward a new solar system employing a solar chimney together with an evaporative cooling cavity. The numerical experiments showed that this integrated system with proper configuration was capable of providing good indoor conditions at the daytime in a living room even at a poor solar intensity of 200W/m^2 and high ambient air temperature of 40◦C.As such, this technique was suitable to supply the cooling load in the moderate and arid climates. The ventilation rate was influenced by solar radiation, ambient temperature, as well as geometrical configurations of both the solar chimney and the evaporative cooling cavity. The numerical experiments also indicated that the use of solar chimney with variable inlet dimensions was a way to control the air change rate per hour and the air temperature of the room. It was suggested that a combination of the proposed system with a conventional air conditioning system would help to create a reasonable indoor environment for human thermal comfort as well as to be energy efficient and environmentally friendly.

Raman et al. [17] verified a passive solar house based on the unification of solar chimneys for heating, cooling and ventilation in composite climates. The passive model 1 consisting of a set of two solar chimneys, an evaporative cooler (for summer) and added wall insulation, performed well for winter, but the summer cooling was not adequate. Consequently, a second passive model 2, which consisted of a south wall collection and a roof duct cooled from above by a sackcloth evaporative cooling system, was constructed and monitored for one year. The thermal performance of passive model 2 was distinctly better than that of model 1. The room maintained a temperature of about 28◦C during summer and about 17◦C in winter, which could be considered as a very satisfactory performance for the composite climates whereas the extra cost of providing passive components and wall insulation was estimated to be about 20% of the cost of a conventional room. Comparing the increasing costs of electricity and deteriorating power situation, the proposed passive system seemed to have good potential.

Chungloo and Limmeechokchai [18] studied the benefits of application of solar chimney on the south roof and cool metal ceiling on the north roof through the experiment in a detached building. The mean cooling potential of the application of combined system was found to be two times higher than that of the solar chimney alone. The application of cool ceiling and solar chimney, which reduced the ceiling temperature by 2–4◦C, did not only increase the circulation in the upper and lower regions of the room but also reduce the air temperature in the room by 0.5–0.7◦C, which could increase the comfort opportunity. The benefit of cool ceiling was also recognized by the increase of volume flow rate of air in the application of cool ceiling comparing to the decrease of volume flow rate of air in the application of precooled air to the room. Dai et al. [19] presented a parametric analytical study on the Enhancement of natural ventilation in a solar house induced by a solar chimney and a solid adsorption cooling cavity. Theoretical analyses were carried out to investigate the ventilation in the solar house with solar chimney alone, cooling cavity alone or with combined solar chimney and solar adsorption cooling cavity, without considering the wind effects. It was established that on a typical day, the solar house comprising of a 2.5 square meter solar chimney, was able to create an air flow rate of more than 150 kg/h for the studied house. In addition, the ventilation rate at night was also increased by about 20% with the solar adsorption cooling cavity. Besides, a solar adsorption cooling could attain a value of 0.12 for COP, which not only increased ventilation, but also provided cooling to the room without any change in humidity. The proposed concept was expected to be useful to be incorporated with a standalone building or with a cluster of buildings for some favorable climates.

Designing Model of EAHE system and Modification to Enhance Performance

The factors that are essential to design an effective EAHE system are pipe length, pipe diameter, pipe material, soil features, air flow, and so on. For flowing of air, blowers can be used. The EAHE system is more functional because it has a precedence over other heating and cooling techniques. The plus points of using this system are minimum air pollution, low maintenance costs and higher coefficient of performance [5]. In last several years, many models were developed to analyze the system performance. There are two ways to analyze the EAHE systems. One way is to calculate the conductive heat. The heat is shifted from the pipe to the ground mass. Another way is to calculate the convective heat. This heat is transferred by the circulation of air to the pipe. It changes the temperature and dampness of the air. The assumptions that are considered to create models and explore thermal performance of EAHE systems used for cooling and heating applications of the buildings are as follows: The pipes which are used in EAHE are of uniform cross section [20].Thermal resistance is neglected because the pipe thickness is very small [21].The soil is isotropic which surrounds the pipe. It has a thermal conductivity, homogenous in nature [21-23].Pipe radius is small, so the thermal effect of the soil which surrounds the pipe, will be neglected [22]. No freezing or evaporation of soil is taking place [23].The pressure is reckoned as one atmospheric pressure [24].The radiation of sun is considered as constant [25].

The temperature on the pipe surface is uniform in axial directions because the temperature profile of it is affected by the appearance of the pipe [26].

Mihalakakou et al. [27], Bojic et al. [28], Ghauthier et al. [29], and Hollmuller and Lachal [30] have published papers on more complete and dynamic models for earth-air heat exchangers Kabashnikov et al. [31] presented an effective mathematical model for calculating the temperature of the ground and air in a ground heat exchanger for ventilation systems. The model was established on the representation of temperature in the form of the Fourier integral. Parametric study was performed to investigate performance behavior of EAHE by taking into account the air flow rate, variation in length, diameter of tubes, depth of burial, and spacing between tubes. Santamouris et al. [32] offered a fresh integrated method to calculate the influence of the earth-to-air heat exchangers to the cooling load of the buildings. The method was based on the principle of balance point temperature and permitted the calculation of the hourly value of the balance temperature of the building as well as the daily cooling load and the contribution of the buried pipes. Mihalakakou et al. [27] developed a mathematical model based on heat conduction equations and on the energy balance at the ground surface. It was concluded that the model can predict ground temperature at the surface and at various depths with sufficient. Sehli et al. [33] proposed a one-dimensional numerical model to check the performance of EAHEs installed at different depths. The effects of Reynolds number, installation depth, and form factor on the performance of EAHE system were investigated through the parametric analysis. The form factor was defined as the ratio of length of pipe to diameter of pipe. It was observed that with increase in installation depth and form factor the outlet air temperature decreases while with increase in Reynolds number the outlet air temperature increases. Finally, concluded that EAHE systems alone are not sufficient to create thermal comfort but can be used to reduce the energy demand in buildings, if used in combination with conventional air-conditioning systems. De Jesus Freire et al. [34] presented a study considering the use of a heat exchanger with a multiple layer configuration, namely, comparing it with a single layer of pipes and describing the major performance differences. After analysis, it was concluded that the heat exchanger power increases with the layers depth until 3m and that the more efficient distance between layers should be kept at 1.5m. When the multiple layer configurations are adopted, it was verified that maintaining similar transfer areas and velocity flows incurs a decrease of 3–6% in the duty delivered by heat exchangers with two and three layers respectively, when compared to heat exchangers with a single layer. However, this corresponds to a decrease of 50% and 67% in the area needed, respectively. Lee and Strand [26] developed a new module and implemented it in the Energy Plus program for the simulation of earth tubes. A parametric analysis was carried out using the new module to investigate the effect of each parameter on the overall performance of the earth tube under various conditions during cooling season. It was concluded that if properly designed an earth tube can save more than 50% of the total cooling load in the cases presented in their paper, depending on the weather and soil conditions. However the earth tube alone cannot replace conventional air-conditioning system in these case studies; it can considerably reduce the cooling load in buildings.

Different Calculations on EAHE System

There are several parameters to design an effective EAHE system as pipe length, pipe diameter, pipe material, soil features, air flow etc. For flowing of air, only blowers will be used. The EAHE system is more serviceable because it has a precedence over other heating and cooling techniques. The plus points of using this system are minimum air pollution, low maintenance costs and higher COP. In last several years, many researches were done to improve the EAHE systems. Many models were developed to analyze this system. There are two ways to analyze the EAHE system. One way is to calculate the conductive heat. The heat is shifted from the pipe to the ground mass. The way is to calculate the convective heat. This heat is transferred by the circulation of air to the pipe. It changes the temperature & dampness of the air.

There are a few computer modeling tools as TRNSYS, Energy plus etc. that have EAHE module which can work really good. But these tools are analysis tools, so it is little bit slowly to be used as designing tools. Nowadays, computational fluid dynamics (CFD) is in vogue because of it's user friendly interface. CFD runs on a very simple rule. It discrete the whole system in smaller grids and occupy equations applied on those separated elements. It governs equation to get solutions of flow parameters, distribution of pressure and gradients of temperature. CFD saves both time and cost by reducing required experimental work. There are different papers, which are published on different design process of the EAHE systems. Most of the papers are based one-dimensional heat conduction because it is quite simple and easy to get results. That is why one dimensional heat transfer problem is more popular than two dimensional or three dimensional problems. These two dimensional or three dimensional problems are more complex and progressive in nature. Because of these reasons, those are still rejected by the designers for not being suitable.

The main applications of EAHE is in greenhouses, residential/commercial buildings, livestock houses and space conditioning. Several researchers made several assumptions on EAHE systems assuming the energy-balance equations by writing and modeling. The major presumptions by the researchers to make a model of EAHE system connected to the greenhouses are:
The greenhouse seems to be in a steady state condition.
The heat transferred from the green house walls to the roof can be negligible due to small value.
The heat capacity in the air of the greenhouse can also be neglected.
The air flow in the buried pipe will be uniform along it's length.
No heat will be transferred from the sides of the pipe.
Inside a greenhouse, the specific heat exerted by the plants will be taken.

These assumptions are considered to create models and explore thermal performance of EAHE systems used for cooling and heating applications of the buildings are as it follows.
The pipes which are used in EAHE are of uniform cross section.
Thermal resistance is neglected because the pipe thickness is very small.
The soil is isotropic which surrounds the pipe. It has a thermal conductivity, homogenous in nature.
Pipe radius is small, so the thermal effect of the soil which surrounds the pipe, will be neglected.
No freezing or evaporation of soil is taking place.
The pressure is reckoned as one atmospheric pressure.
The ground surface temperature can be considered as ambient air pressure.
The radiation of sun is considered as a constant.
The temperature on the pipe surface is uniform in axial directions because the temperature profile of it is not affected by the appearance of the pipe.

The dormant heat exchanges are not regarded, which means there is no work for water infiltration. The temperature of air is desired to remain over the dew point.

One Dimensional Analysis of EAHE System

The modeling is more effective tool to predict the effects of operating parameters as pipe radius, flow rate of air, pipe length and depth of burial on the cooling & heating and the thermal performance of EAHE systems. By this day, there are many researchers who worked on several number of studies to calculate the models for earth - air heat exchanger system. It is started to analyze the EAHE systems by developing the one-dimensional (1D) models. In one-dimensional model our target is to derive a relation between the inlet and outlet temperatures that was used. Eight models were studied by Tzaferis et al. All studies found approximately the same result. It indicates that the performance of the earth - air heat exchangers is also characterized by a steady-state one dimensional model. Many researchers have revealed papers on a lot of dynamic and complete models of earth-air heat exchangers as Mihalakakou et al. , Bojic et al. , Hollmuller and Lachal, Ghauthier et al. Kabashnikov et al. conferred a good mathematical model for calculating the temperature of the air and ground in an exceedingly ground heat exchanging device for ventilation systems. This model was supported the illustration of temperature in sort of the Fourier integral. The model was easy and simple to calculate and might be referred for designing concerns.

Santamouris et al. conferred a brand new integrated technique for calculating the contribution of earth - to - air heat exchangers to the cooling load of the buildings. This method is found that it is of decent accuracy and therefore, may be used throughout the predesign and design section for the orientating of the buried pipes.

Ben Jmaa Derbel and Kanoun had given a mathematical model predicting that the soil temperature of subsurface of the region of Sfax, Tunisia and affirmed this by measuring the ground temperatures. A model has been developed that was named as earth fluid pipe. Then, the model of the subsurface temperature has been utilized in synchronizing the model known as the earth fluid pipe to assume the energy transfer performance. The experimental study which was done by Thanu et al. was has been validated against the earth - air - pipe model. Ghosal et al. developed an entire numerical model for assuming EAHE and ground air collector which integrated with the greenhouse situated within the premises of IIT, India for selecting an appropriate heating technique within the composite climate of India. For this model, finally the ground air collector was chosen as an acceptable possibility for heating of greenhouse within the composite climate of India.

Sehli et al. projected a one-dimensional numerical model to visualize the performance of EAHE's which is put in at completely different depths. The consequences of Reynolds number, form factor & installation depth on the performance of an earth - to - air heat exchanger (ETHE) system were investigated through the constant analysis.

Kumar et al. developed a temporary numerical model retained on coupled simultaneous heat and mass transfer equations to explain the thermal performance of EAHE system. The development of this model was done by FFT (MATLAB) and numerical techniques of finite-difference. This present model may simply combined to totally different greenhouse and building simulation codes.

De Paepe and Janssens developed a one-dimensional analytical methodology to investigate the influence of the designing parameters of heat exchanger on thermohydraulic performance. For this, the characteristic dimensions became therefore independent of climatological conditions. It allowed the designers to settle on the earth - air heat exchanger configuration with the best performance.

Two Dimensional Analysis of EAHE System

The approximation of Cucumo et al. is that the performance behavior of EAHE is buried at completely different depths. Development of this model is the answer of mass and heat balances for air through the buried pipe, taking into consideration an appropriate temperature profile within the ground. This can be determined by two methods. One is stablished on Green's function another one is based on the principle of superposition.

Pfafferott presented a research paper that deals with the performance of three EAHXs for mid-European workplace buildings which are in commission and the aim of characterizing their potency.

Normal configurations of a heat exchanger customarily considered as one single layer of pipes requiring an immensely colossal installation area. major drawback can be overcome by utilizing a multiple layer configuration. De Jesus Freire et al. submitted a study in which he considered the utilization of a heat exchanger with a numerous layer configuration, to be specific, contrasting it and a solitary layer of pipes and portraying the real execution contrasts. It was found that a one-dimensional discrete model can react acceptably to a performance investigation of compact buried pipe frameworks, creating results altogether quicker than the dimensional model, inside a great perfection. This format of model is exceptionally suitable given the present constraints in urban spaces.

Al-Ajmi et al. built up a hypothetical model of an EAHE for foreseeing the outlet air temperature and cooling capability of the devices in a hot and dry atmosphere. This model was approved against three other studies: Dhaliwal & Goswami, Mihalakakou et al. and Shingari.

An outline of one-dimensional figuring models is given in Table 1.

The practice of two dimensional models of EAHE systems came handy during the 1990s.Two-dimensional (2D) models permit computation of ground temperature at surface and at various profundities of depths. The limited component programs are utilized as a part of 2D models to take care of two-dimensional conduction issues of EAHE systems. Badescu introduced a straightforward and simple ground heat exchanger model. The thermal conduct of the heat exchanger was displayed by method for a numerical transient dimensional approach. This methodology permits to compute the ground temperature profile at the surface and at different depths conveyed by the ground heat exchanger depends significantly on various outline parameters pipe’s depth, material and distance across.

Zhao et al. presented a study to analyze the thermal execution of immersed soil around coaxial ground-coupled heat exchanger (GCHE). The test examination was conducted by method for artificial glass micro balls as permeable medium. The results demonstrated that heat exchange for the most part happens close to the external mass of coaxial GCHE and slopes to stabilize at far-field.

Li et al. introduced an inward heat source model of underground heat exchanger taking into account the mass and heat transfer hypothesis in soil. Various variables, for example, dampness development in soil, soil sort, and soil property were taken into record to develop the model. The heat exchanger of underground was streamlined as the equal internal heating source term in the model.

Kumar et al. developed the idea of artificial neural system and a PC design tool that can offer assistance to the originator to evaluate any part of earth - to - air heat exchanger and conduct of the final setup. Study was predominantly focused on those perspectives identified with the latent cooling or heating execution of the building. They have created two models for this reason, specifically, intelligent and deterministic. The deterministic model was created by breaking down all the while coupled heated and the mass move in ground though the insightful model was an improvement of information driven artificial neural network model. Length, dampness, encompassing air temperature, ground surface temperature, ground temperature at entombment depth and air mass flow rate were taken as variables affecting the thermal execution of the earth - to - air heat exchangers. The model was accepted against experimental information sets. The intelligent model anticipated earth - to - air heat exchanger outlet air temperature with a precision of ±2.6%, while the deterministic model demonstrated a precision of ±5.3%.

Tittelein et al. introduced another numerical model of earth-to-air heat exchangers. The discretized model was tackled utilizing the response factors method as a part of request to decrease computational time. Every reaction factor was computed by using a limited components program that explains 2D conduction issues. Benefits of this model incorporate the way that computation time was lessened by the utilization of response factors it was exact for a short time period (1-day) and a long requesting period (1-year) as the system was discretized into "n" sections perpendicular to the exchanger pipe that was not the situation for the models taking into account a discretization of the ground in concentric cylinders and axial meshes and each sort of soil qualities (an-isotropic, non-homogeneous and so on.) and also, of geometry can be considered because of the response factor count in a 2D finite components program.

System capability to assure the required indoor condition, dimensions of solar collector and EAHE and cooling demand. In a paper published by Mehri Maerefat a sample model was established for the whole procedure. Dimensions and specifications are given as follows - the room $4 \times 4 \times 3.125$ m in dimensions, without air infiltration and has a lowest cooling requirement of Q=116 watt. This is the demand of a room with adiabatic walls which has 1 person is resting inside it. The cooling demand is changed at the range of 116-1500 watt in the calculations.

A solar chimney having 4m length, width of 1m, air gap depth of .3m and inlet of .4×.4 m is presumed .This dimensions are selected based on certain references. a detailed study on the south facing solar chimney in Tehran ,having 35.44 degree north latitude position has found the optimum angle of 50 degrees to capture more radiation .The cooling pipe of EAHE is a

PVC pipe with 25m length,.01 m thickness and inside dia. of .5m is buried 3m below the soil surface. According to the model developed by N.K. Bansal undisturbed soil temperature at a depth of 3m is approximated to be 19 degree Celsius for a dry shaded soil surface condition and it is considered to be the heat sink temperature .Usually only one EAHE suffices to provide the necessary cooling load, but in severe hot conditions more cooling pipes may be used.

Effective Dimensions of the EAHE System and and Effect on Environmental Conditions

Some dimensions that affect the performance of the EAHE system are absorbing surface of the solar collector, cooling surface of the EAHE that arranges proper heat removal from the air flow to soil as stated in the paper of Mehdi Maerefat in his paper on passive cooling in buildings. A comparative survey has showed that the required number of solar collectors and EAHE are minimum when diameter is 0.5 m. The variation in lateral surface area are made by increasing the length of pipe [15]. In a review article by Bisoniya we come across some facts for modeling the EAHE system as example the pipe used in EAHE is of uniform cross section.it has also been found that the long EAHE with the length more than 20m should be employed to provide the thermal comfort conditions. Results show that when the ambient temperature and cooling demand are high, although providing thermal comfort is difficult, proper configuration could access with good indoor condition even in the poor solar intensity of 100 Watt per square meters and high ambient temperature of 50°C [20]. Another paper by Haghighi stated that an air gap of 0.2m is considered as the maximum air gap value. It is seen that at high solar intensities there is a remarkable increase in ACH. In here it is discussed that size of the room can change system performance and the diameter of the pipe and length of the pipe effects on the system performance. The results show that the required number of EAHEs and solar chimneys should be increased to retain the thermal comfort condition when the roof size and the heating conditions are increased simultaneously [15].

Result and Analysis

An analysis of the performance of a coupled cooling system with earth-to-air heat exchanger and solar chimney shows that in summer time the when outdoor temperature was 25°C to 34°C, the indoor remained at 21.3 °C to 25.1 °C, the coupled system provided maximum total cooling capacity of 2582W and maximum sensible cooling capacity of 1624W which satisfied the building design cooling load [5].

In a study of solar chimney assisted with wind tower system performed by N. K. Bansal, we see that effect of solar chimney reduces as available wind ambient velocity reduces. For wind speed 1m/s, mass flow rate 0.75 to 1.3kg/s can be achieved and with air exchange of 35 to 73 ACH. 35 ach is possible if cooling tower alone can cool ambient air by 5°C achieved by evaporative cooling [35].

Another study on calculation models on EAHE systems showed, for the pipe of 23.42m in length and 0.15m diameter, cooling in the range of 8.0–12.7°C has been observed in summer for the flow velocity of 2 to 5 m/s. Investigations on steel and PVC pipes shows no significant affect according to material of pipe. The system provided 4500MJ of cooling effect while 3109MJ cooling is achieved by integrating by evaporative cooler [20].

Another research on passive cooling of buildings using integrated EAHE and solar chimney says that the integrated system provided indoor thermal comfort condition, the temp is retained at 28.15-31.94°C with 3-7ACH which secures the required ventilation rate. Higher cooling can be achieved with longer and more pipes [15].

In a research University of Athens of using EAHE for cooling, it showed that in university building the maximum temperature drop was about 10°C compared to maximum ambient temperature. In paper warehouse the mean temperature drop achieved was 5°C with two tubes of 0.315m buried under 2m soil with lengths 50 m and the air velocity was 8m/s [13].

Now let’s talk about the results about the experiments that we carried out-

<u>At the beginning of the experiment –</u>

3 k type thermocouples was placed inside the soil beside the thermo-fluid lab of IUT.

Data were taken for 6 months to see how temperature profile changes in soil under 3 different depths.

The data were placed in a graph to evaluate if efficient heat transfer was possible .

The graph shows almost around 10 degree celsius difference between ambient and soil under 3m depth which is perfect for proper heat transfer.

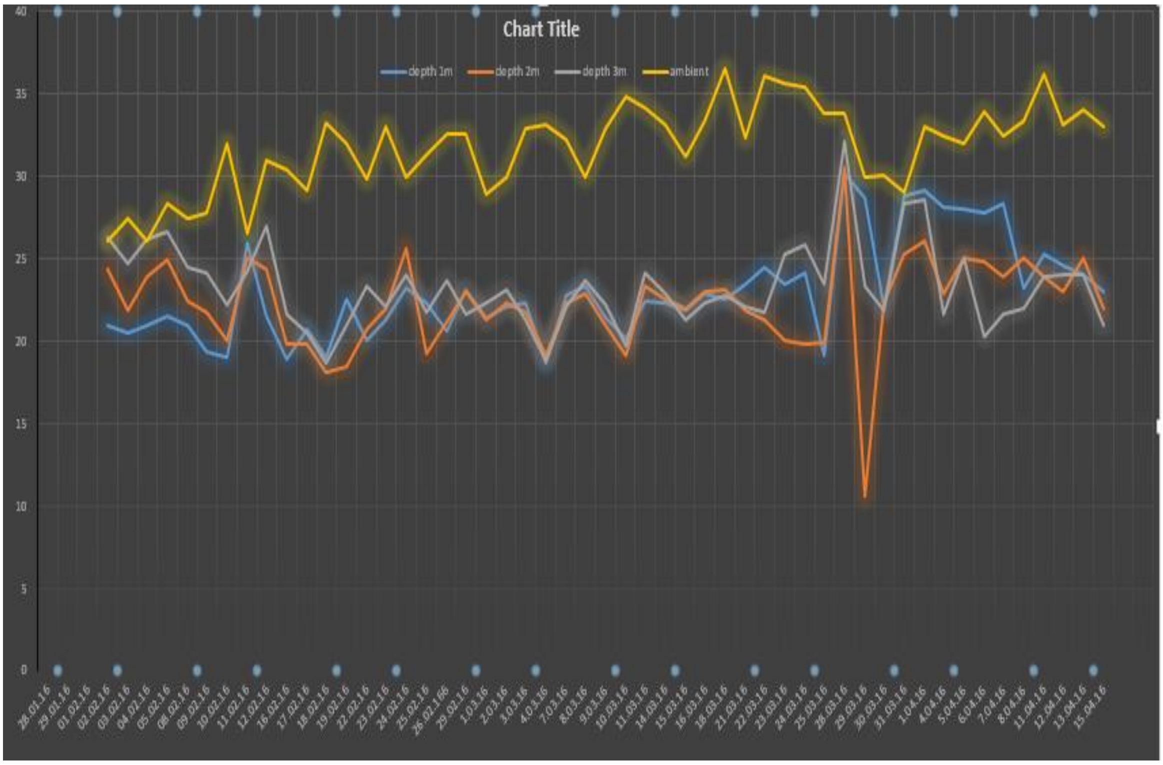


Figure 3: Temperature Profile Observed in atmosphere and under three different depths of soil in IUT in summer

The simulation was done in segments -
Flow through EAHE tubes
Air circulation and exhaustion in the controlled test facility
Flow through solar collector and solar chimney
Flow through total integrated system and efficiency

SOFTWARE: ANSYS FLUENT
VISCOUS MODEL USED:
K –EPSILON (2 EQN MODEL) [Lower Speed]
K – OMEGA (SST MODEL) [Higher Speed]
RADIATION NEGLECTED FOR SIMPLICITY IN INITIAL MODEL

\

BOUNDARY CONDITIONS:

Inlet

Velocity: 3 m/s and 30 m/s

Gauge Pressure: 0 Pascal

Inlet Temperature: 300K, 305K, 310K

Outlet

Bound. Cond. Type: Pressure Outlet Gauge Pressure: 0 Pascal

Gauge Pressure: 0 Pascal

Pipe Wall

Pipe Wall No Slip Wall Operating Pressure: 101325Pa

Operating Pressure: 101325Pa

Wall Condition

No Slip Wall

Human Condition

stationary wall with heat flux as calculated

Note: It was not necessary to define or model the material of human as we used a fluid cavity in the shape of human instead of a solid in the form of human ,this also simplified the simulation

SIMULATION RESULTS:

Simulation was done in 3 different temperatures of ambient air while entering the buried tubes and corresponding exiting air temperature was recorded after heat transfer by simulation.

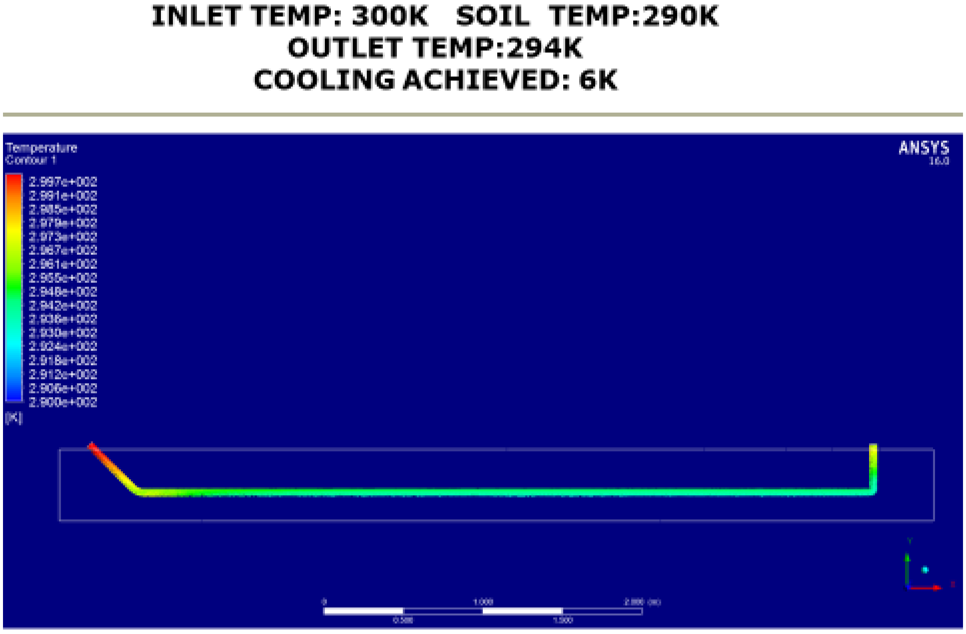


Figure 4: Simulation of achieved cooling inside EAHE with an atmospheric temperature of 300K without insulation

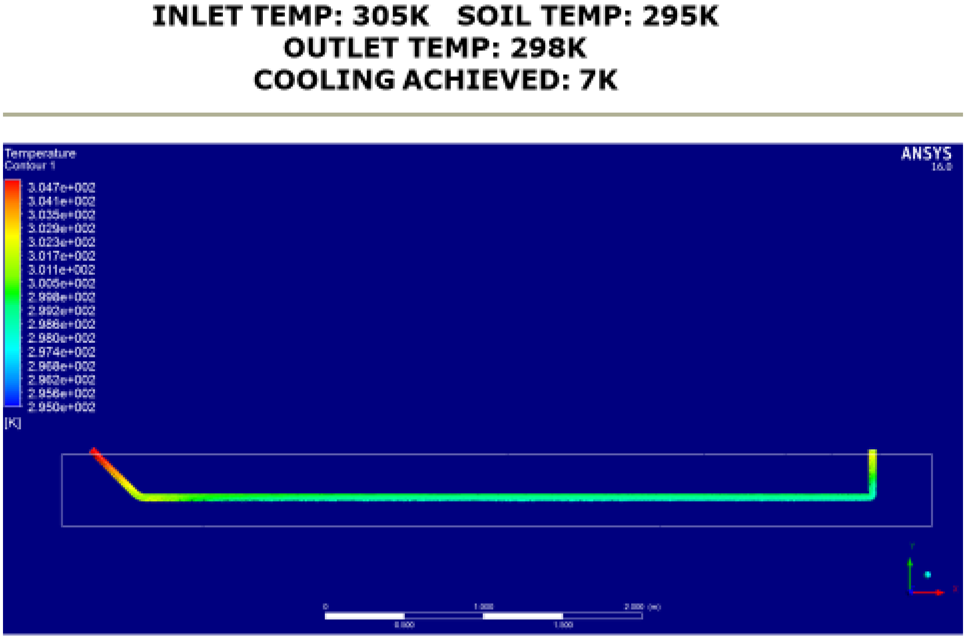


Figure 5: Simulation of achieved cooling inside EAHE with an atmospheric temperature of 305K without insulation

INLET TEMP: 310K SOIL TEMP:290K
OUTLET TEMP: 304K
COOLING ACHIEVED: 6K

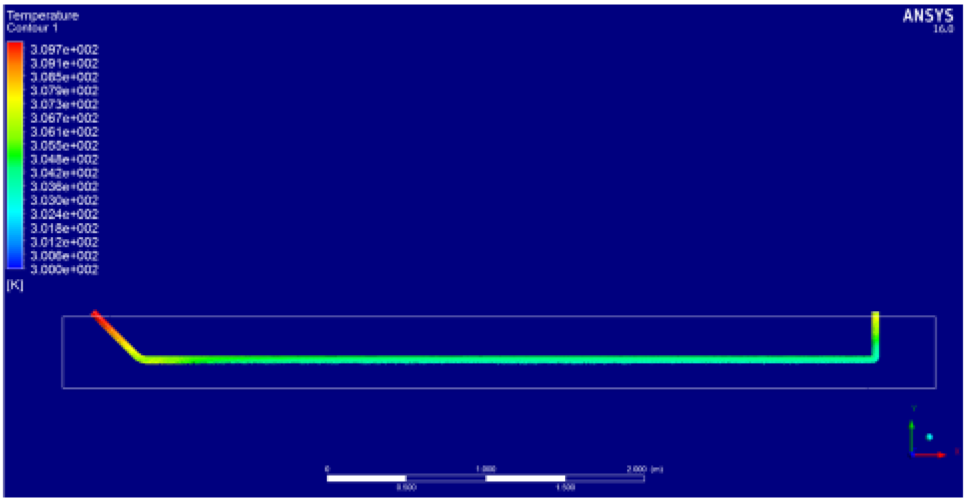
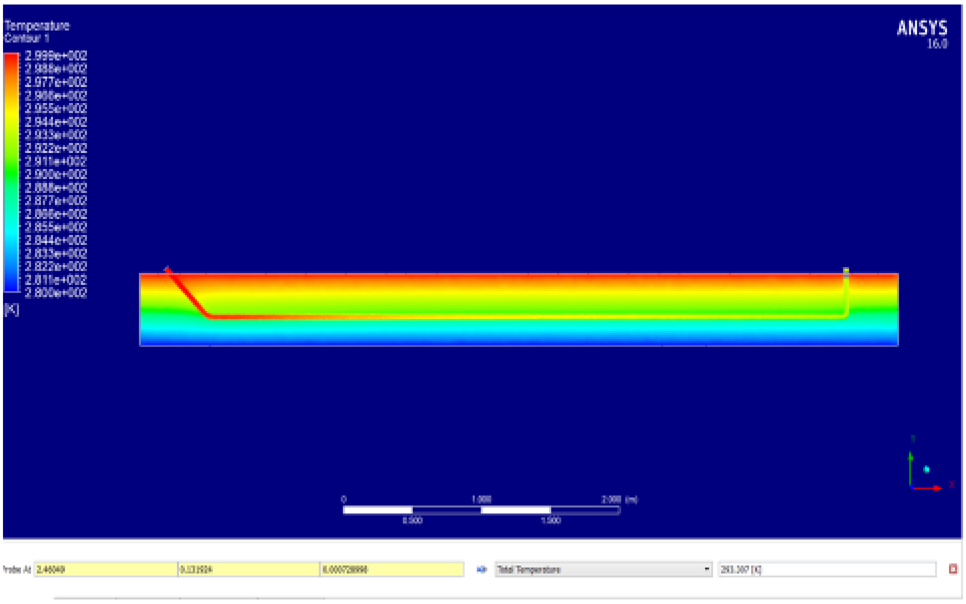


Figure 6: Simulation of achieved cooling inside EAHE with an atmospheric temperature of 310K without insulation

INLET TEMP: 300K SOIL TEMP:290K
OUTLET TEMP:294K
COOLING ACHIEVED: 6K



Probe At 2.46049 0.131924 0.000728998 Total Temperature 291.397 [K]

Figure 7: Simulation of achieved cooling inside EAHE with an atmospheric temperature of 300K with insulation

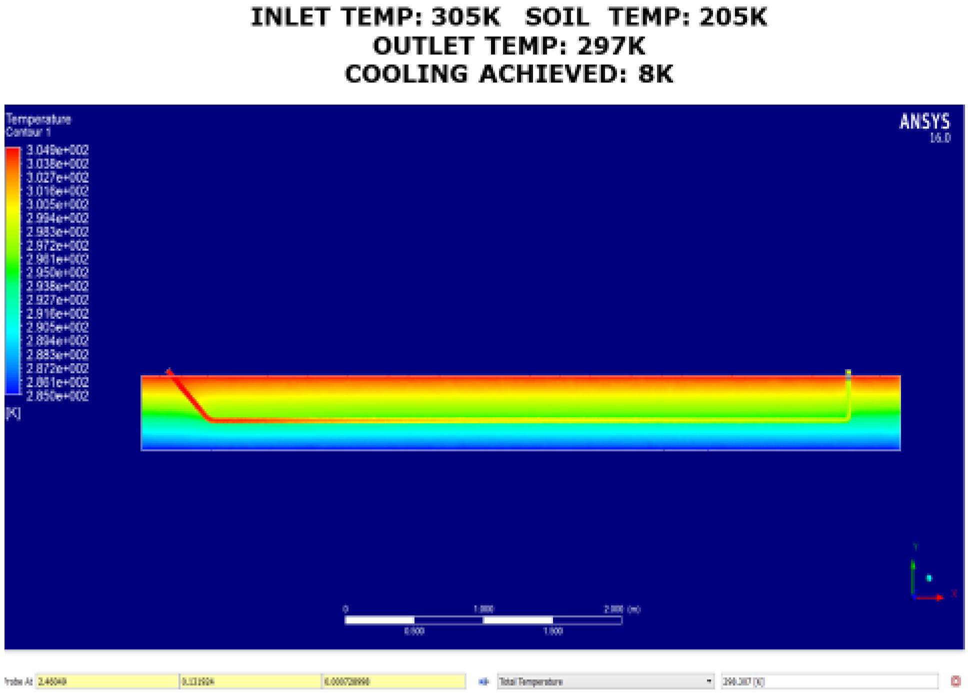

INLET TEMP: 305K SOIL TEMP: 205K
OUTLET TEMP: 297K
COOLING ACHIEVED: 8K

Figure 8: Simulation of achieved cooling inside EAHE with an atmospheric temperature of 305K with insulation

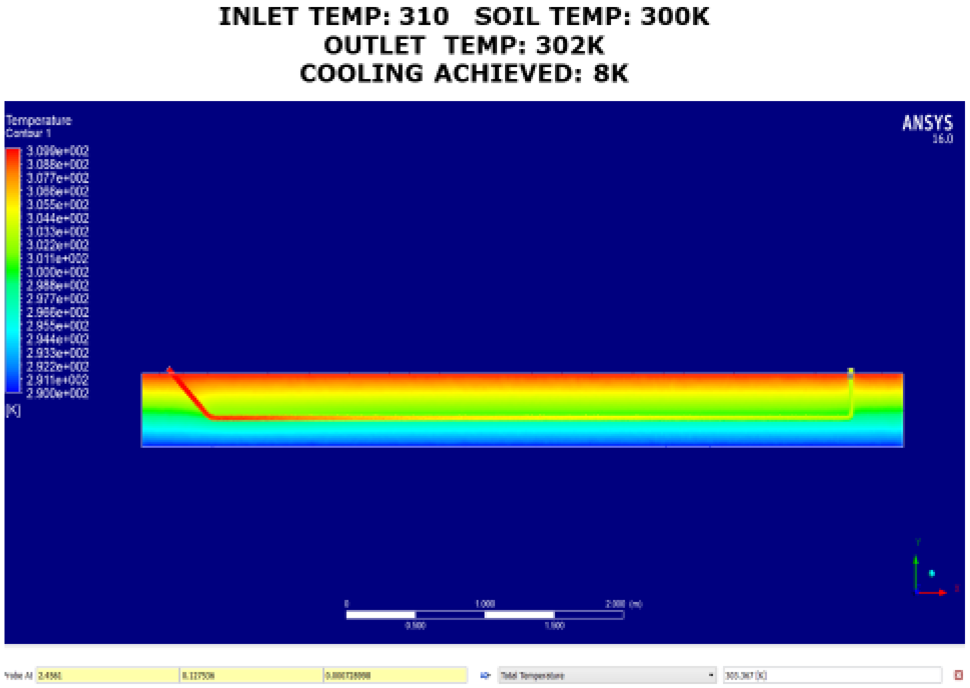
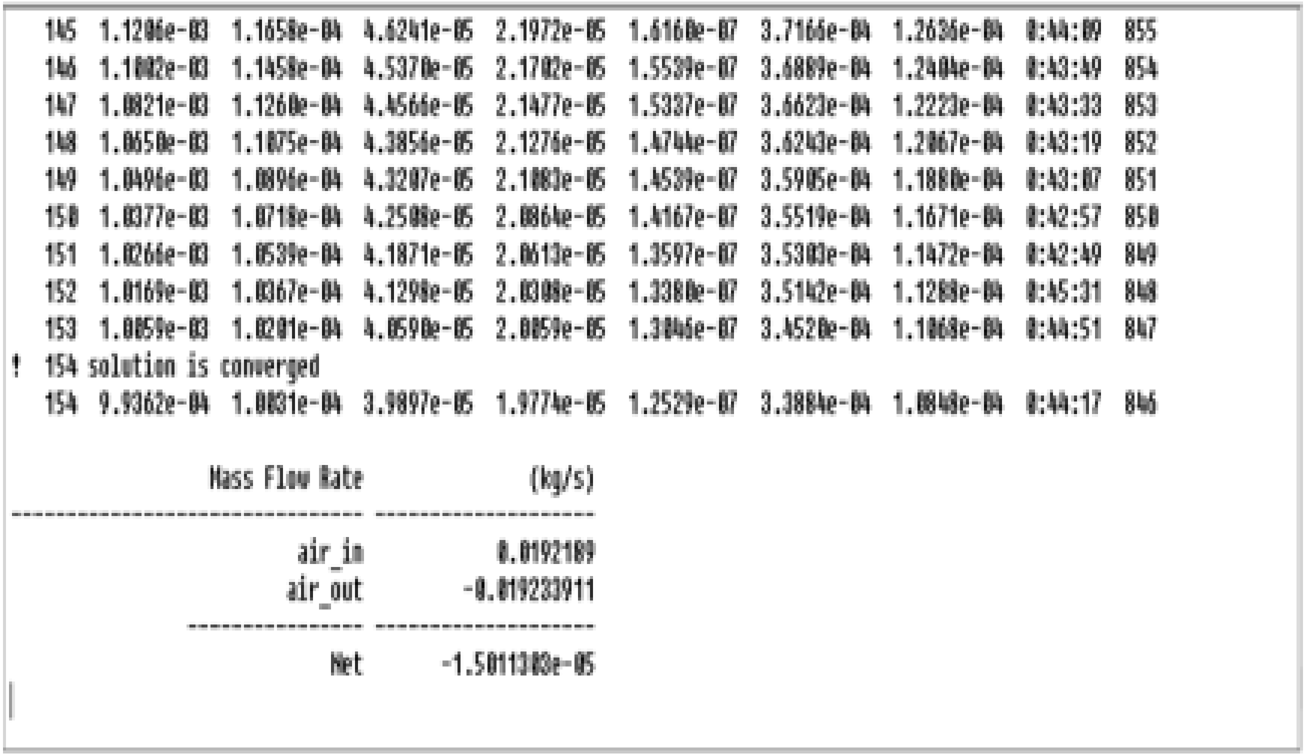

INLET TEMP: 310 SOIL TEMP: 300K
OUTLET TEMP: 302K
COOLING ACHIEVED: 8K

Figure 9: Simulation of achieved cooling inside EAHE with an atmospheric temperature of 310K with insulation

Continuity Verification



```
   145  1.1206e-03  1.1650e-04  4.6241e-05  2.1972e-05  1.6160e-07  3.7166e-04  1.2636e-04  0:44:09  855
   146  1.1002e-03  1.1450e-04  4.5370e-05  2.1702e-05  1.5539e-07  3.6809e-04  1.2404e-04  0:43:49  854
   147  1.0821e-03  1.1260e-04  4.4566e-05  2.1477e-05  1.5337e-07  3.6623e-04  1.2223e-04  0:43:33  853
   148  1.0650e-03  1.1075e-04  4.3856e-05  2.1276e-05  1.4744e-07  3.6243e-04  1.2067e-04  0:43:19  852
   149  1.0496e-03  1.0896e-04  4.3207e-05  2.1083e-05  1.4539e-07  3.5905e-04  1.1880e-04  0:43:07  851
   150  1.0377e-03  1.0718e-04  4.2508e-05  2.0864e-05  1.4167e-07  3.5519e-04  1.1671e-04  0:42:57  850
   151  1.0266e-03  1.0539e-04  4.1871e-05  2.0613e-05  1.3597e-07  3.5303e-04  1.1472e-04  0:42:49  849
   152  1.0169e-03  1.0367e-04  4.1298e-05  2.0308e-05  1.3380e-07  3.5142e-04  1.1288e-04  0:45:31  848
   153  1.0059e-03  1.0201e-04  4.0590e-05  2.0059e-05  1.3046e-07  3.4520e-04  1.1068e-04  0:44:51  847
!  154 solution is converged
   154  9.9362e-04  1.0031e-04  3.9897e-05  1.9774e-05  1.2529e-07  3.3884e-04  1.0848e-04  0:44:17  846

                  Mass Flow Rate                (kg/s)
-------------------------------- --------------------
                          air_in             0.0192189
                         air_out          -0.019233911
                ---------------- --------------------
                             Net        -1.5011303e-05
```

Figure 10: Verification of Continuity Equation

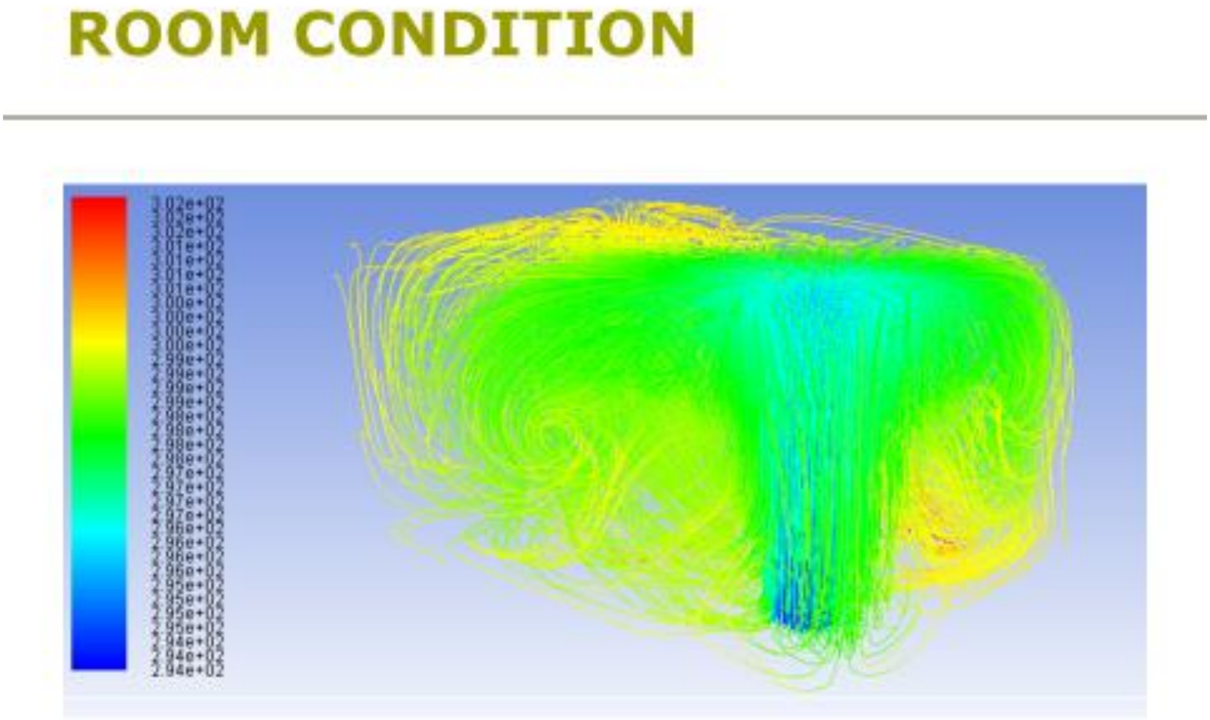


Figure 11: Simulation of Room Condition with only one EAHE pipe outlet

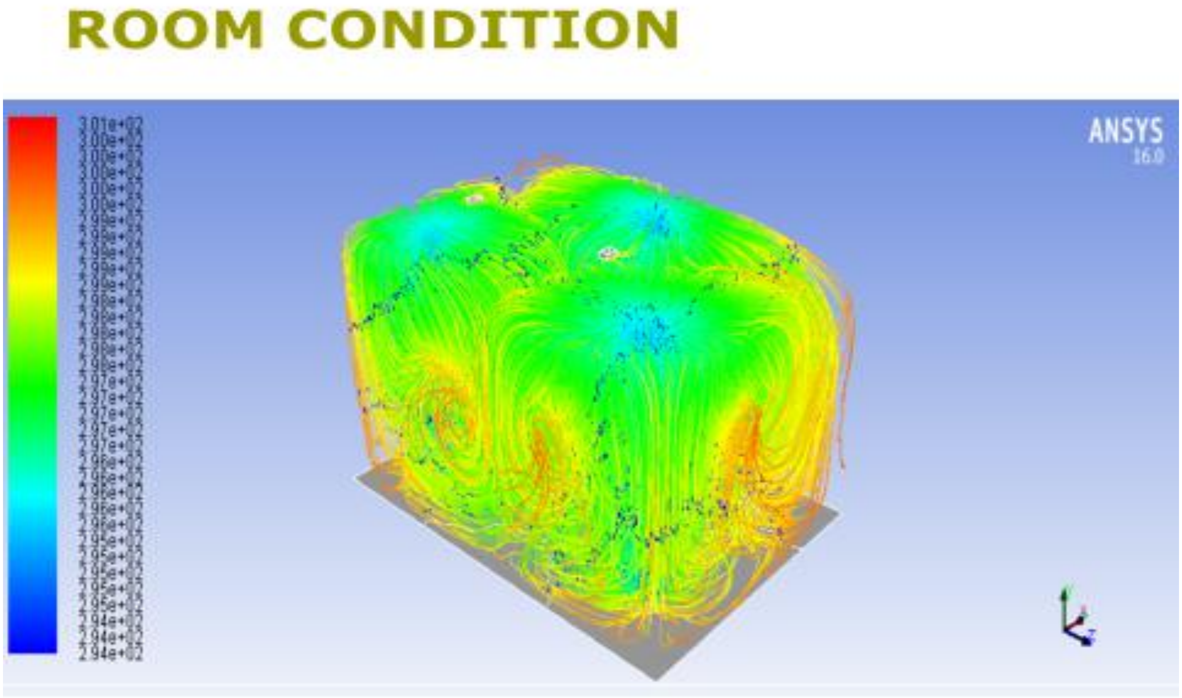
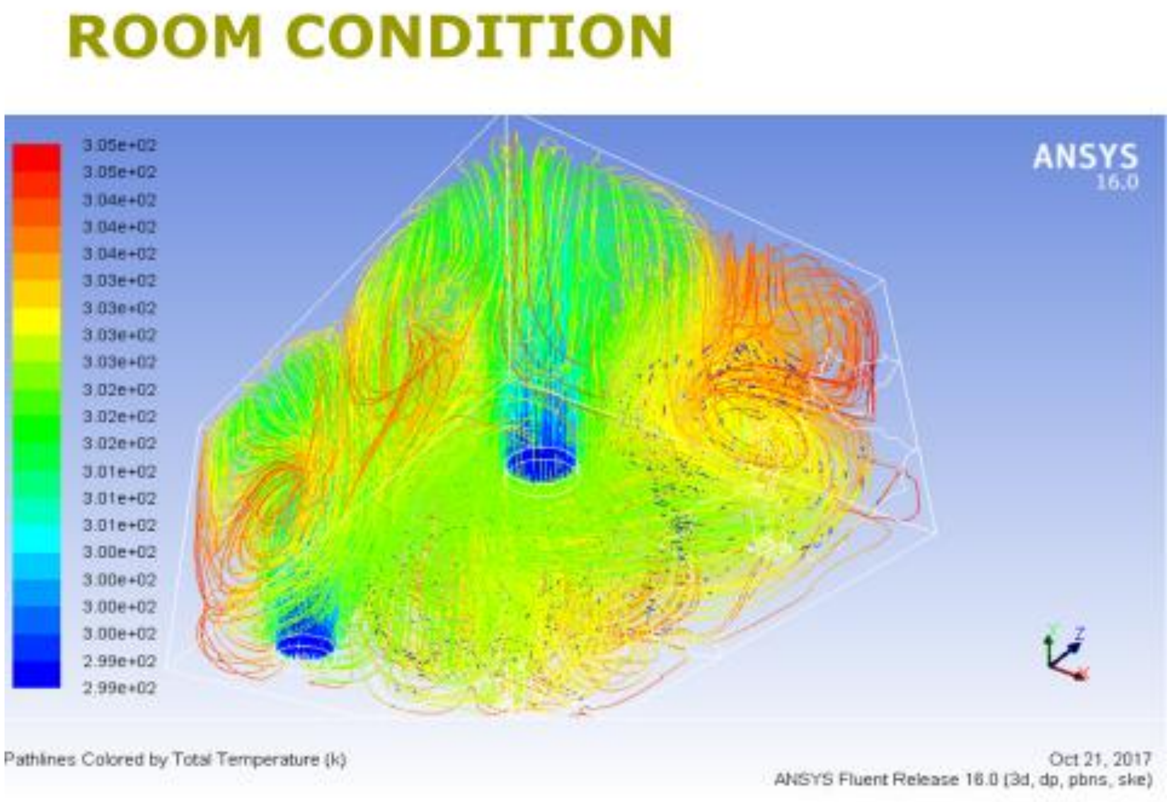


Figure 12: Simulation of Room Condition with three EAHE outlets (top view)

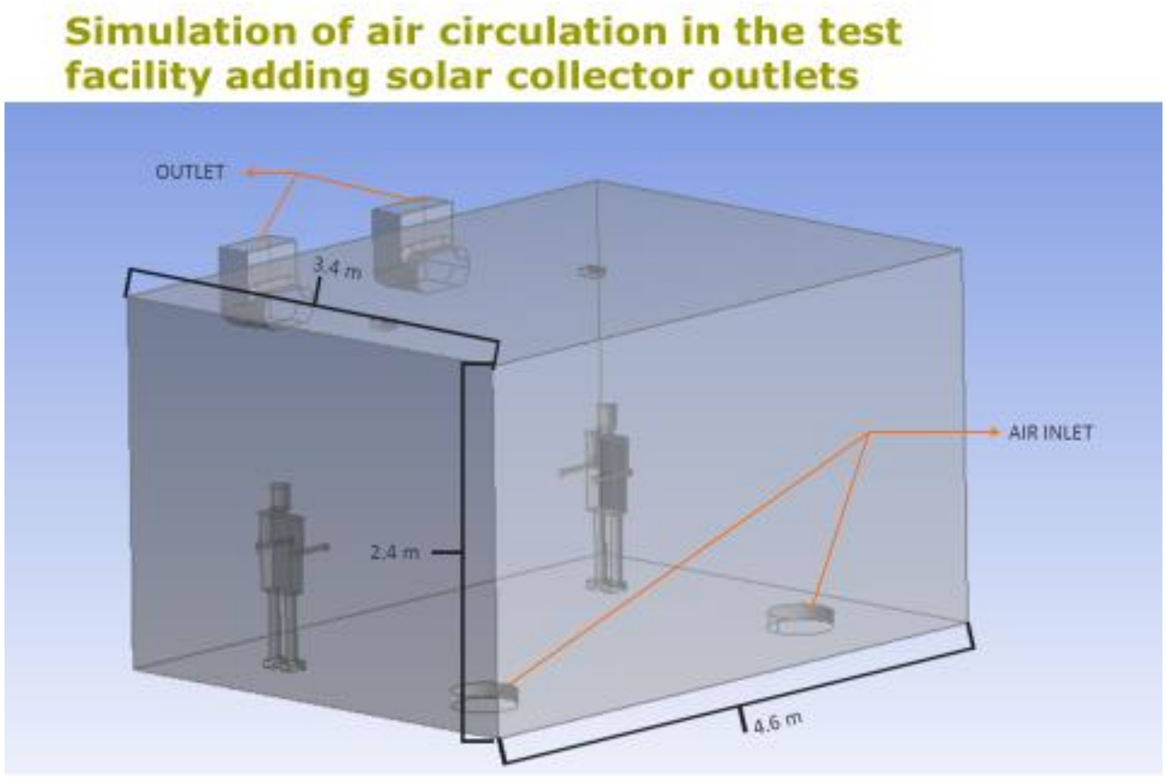


ROOM CONDITION

Pathlines Colored by Total Temperature (k)

Oct 21, 2017
ANSYS Fluent Release 16.0 (3d, dp, pbns, ske)

Figure 13: Simulation of Room Condition with three EAHE outlets (bottom view)



Simulation of air circulation in the test facility adding solar collector outlets

Figure 14: SolidWorks Design for the Room with two person and two Solar Collector Outlets

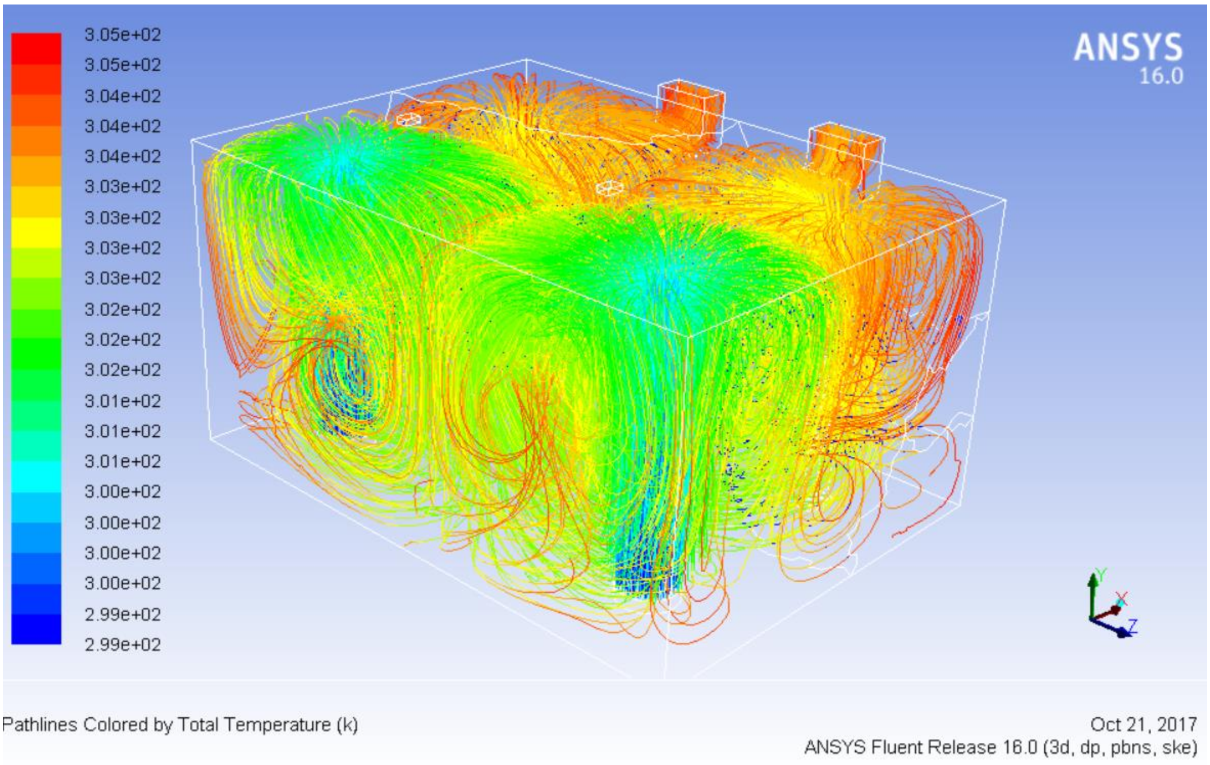


Figure 15: Room Condition after adding Solar Collector Outlets with two EAHE outlets (orthogonal view)

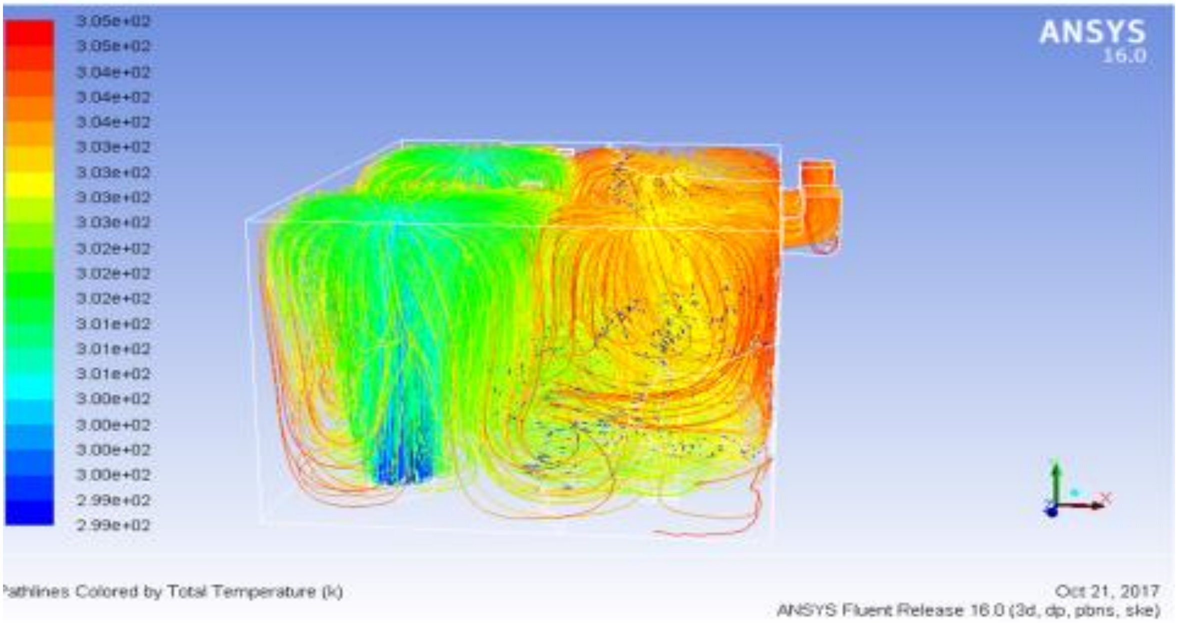


Figure 16: Room Condition after adding Solar Collector Outlets with two EAHE outlets (side view)

Conclusion

According to N.K.Bansal et al the solar chimney works on the basic of an air heating solar collector due to temperature increasing across the chimney which works as an integral part of the passive cooling system [35]. Effects of solar chimney gets reduced at the increase of ambient velocities.in another paper by Mehdi Maerefat [15] regarding passive cooling of building an integrated system of a few number of solar chimneys with one or more EAHE cooling pipe may provide even more thermal comfort conditions and even more cooling demands can be quenched by longer and more cooling pipes. The EAHE system if properly designed can be feasible and economically better to replace conventional air conditioning system as there is no necessity of compressor, chemicals and only blowers are required to circulate air. It was tested in the IUT campus premises about how much heat can be exchanged by the air to the ground and result showed almost more than required heat exchange of air was possible. This resulted in a positive signal to the feasibility of this passive cooling system in Bangladesh. By integrating non-conventional energy sources like solar, wind and more the process can be more efficient and eco- friendly. It is expected that this review paper will be very useful to put emphasis on more research on this field and thus resulting in a more effective and universal passive cooling system using renewable energy sources.

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