Sustainable architecture compatible with renewable energy principles: A mosque building as a case study

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ABSTRACT

The current investigation considers sustainable energy utilization in architecture as novel via future visions for such concept development of. Simulations of ANSYS as software were utilized for a real design of mosque situated in the north of Iraq as study case. Thus, the mosque buildings selection in city of Sulaimaniyah in Iraq as model of application for the clean energy technologies utilize through selecting the building internal space and tests conducting utilizing energy as solar and reviewing its influence on energy providing required via the building and minimizing the waste in consumption of electrical energy which relies on resources as fossil.

The current investigation assuming that the novel constructed foundations of mosque can be enclosed with pipes grid equally distributed through the design. Such pipes are able to be filled in winter with hot water as a replacement for utilizing heaters that consume and cost a large electricity amount. Besides, it displays the achievability of utilizing green energy as unit of heating, particularly if it can cover the installation capital cost in only one year due to the high bills of electricity in Iraq and the capability to preserve energy as solar.

Keywords: Renewable energy, Green building, CFD, Heat transfer, Electricity saving.

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1. Introduction

The systems and standards of sustainability have been represented by many concepts that have been affected by economic, social, and environmental aspects and future prospects for the continuous urban development to create usable buildings through the use of building practices that will not cause long-term damage to the environment. Renewable energies are defined as those energies that are naturally generated and sustainable, and are characterized by being non-depleted and available in nature in an unlimited and sometimes limited manner, but constantly renewable, as well as being clean whose use does not result in any environmental pollution. These sources include energy as solar, which is the main source of energy on the earth's surface [1].

2. The concept of sustainability in architecture

Architecture is one of the main areas that consume a large amount of resources and energy and produce large quantities of consumables and waste, so achieving sustainability in the field of architecture is one of the main challenges for architects, and sustainability is a very important process for all human activities. The goals of sustainable architecture are as follows [2, 3]:

- Efficiency in the use of resources. Energy efficiency
- . • Prevention of pollution.
- Compatibility with nature.

Sustainable construction has been defined as innovation and the management responsible for building a healthy environment based on effective resources and environmental principles. The goal of this type of architecture is to reduce the negative impact on the environment, through energy and resource efficiency [4].

3. Clean energy through heating as solar

Solar central heating or central heating as solar is the central heating provision and hot water from energy as solar by a system where water is centrally heated via utilizng energy as solar thermal and is circulated via networks of central heating pipes, and solar collectors are usually collected on the roofs of buildings, as for heating systems. In regions, collectors may be floor mounted and solar heating as central may include thermal storage of large scale and sizing from storage of daytime to seasonal storage thermal energy [5].

Storage as thermal increases the fraction of solar which is the proportion between the solar gains to the total demand of energy in the system for systems as solar thermal. Solar central heating systems are of well price proportions because of lower price of installation, higher efficiency as thermal and smaller amount of maintenance. In few states i.e., Denmark, plants of solar heating are functioning on scale being large for competing with other heat generation forms.

4. Case Study

A mosque in Sulaimaniyah city, which is located in northern Iraq, was selected for testing using ANSYS Design software Modular 2019 R3, in order to achieve the required goals of reducing the energy spent in the building and relying on sustainable energy by using energy as solar and solar heating. This idea can be applied by laying down hot water pipes on the floor of the required building (mosque in this case). The idea of heat transfer can transform these pipes into heating devices throughout the whole area of the hall. Figure (1) explains the cross section of the selected mosque showing the internal spaces and the design of the mosque. Figure (2) explains the elevation of the selected mosque presenting all the details regarding the heights and dimensions. Figure (3) and figure (4) explain the electrical power drawings and its distribution inside the selected mosque with the detailed of the first floor and the accessories.

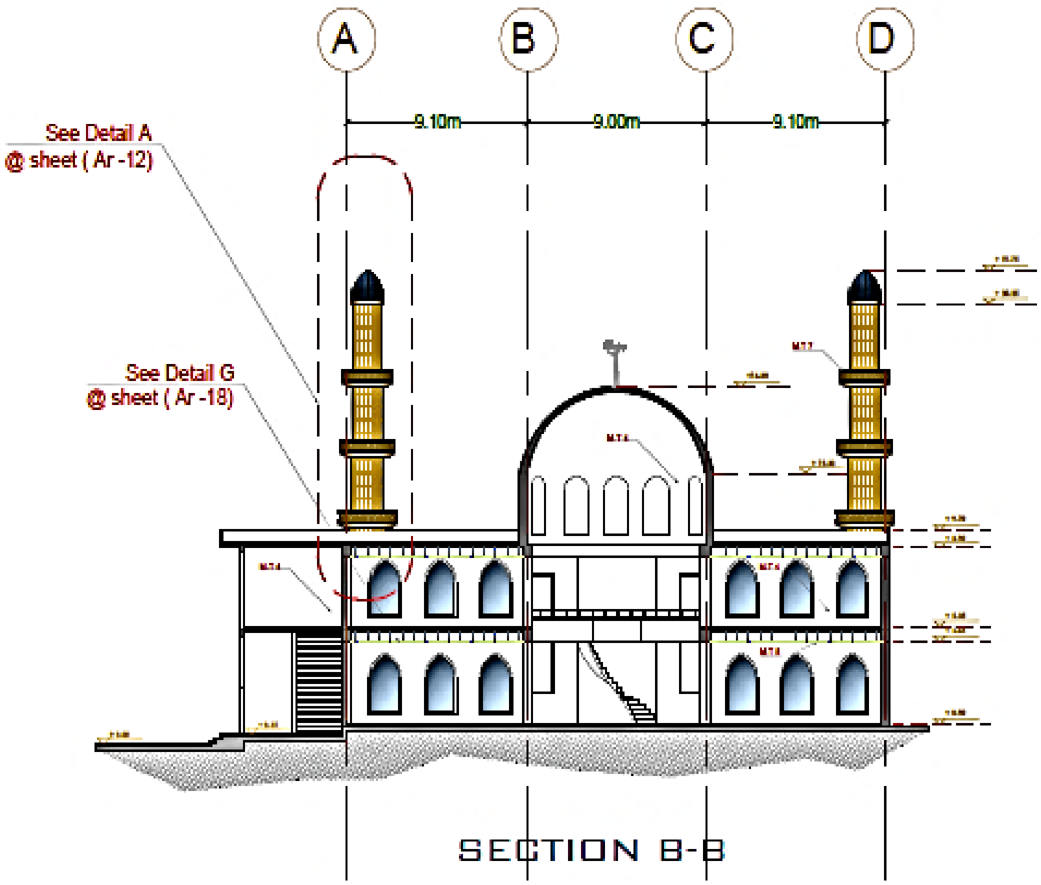

Figure 1. Cross section of the mosque

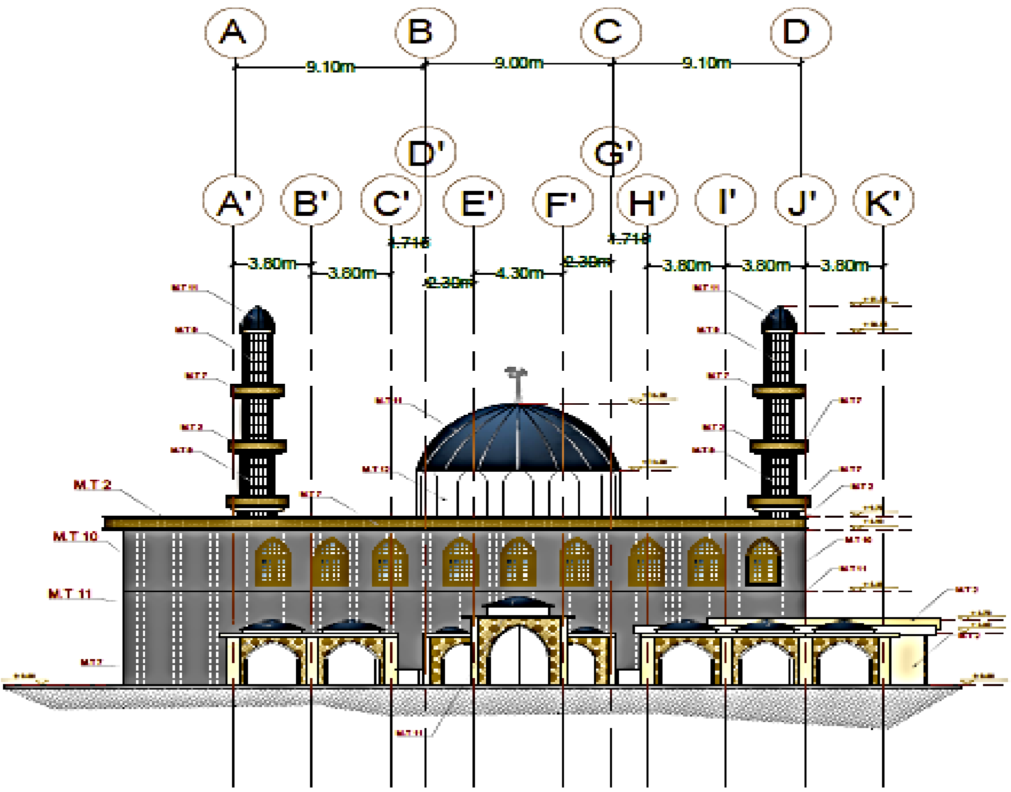

Figure 2. The elevation of the mosque

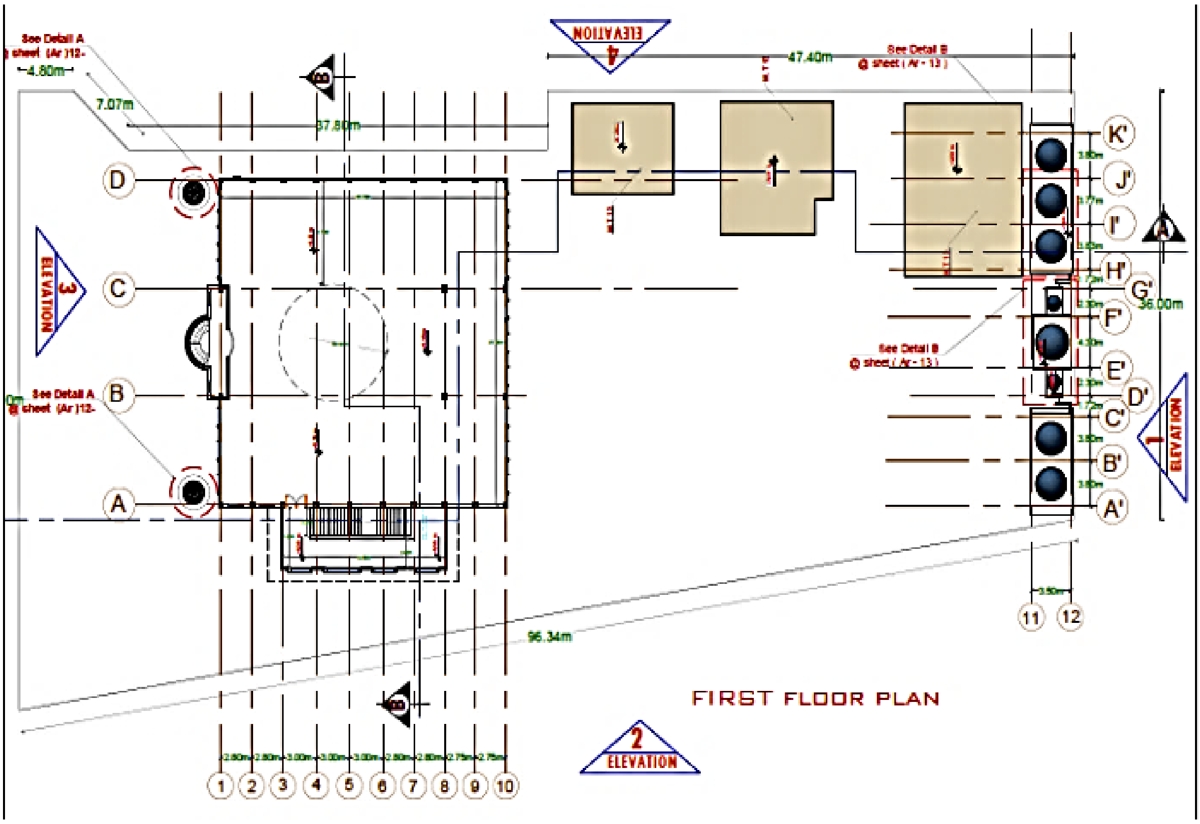

Figure 3. The electrical power drawings of the first floor

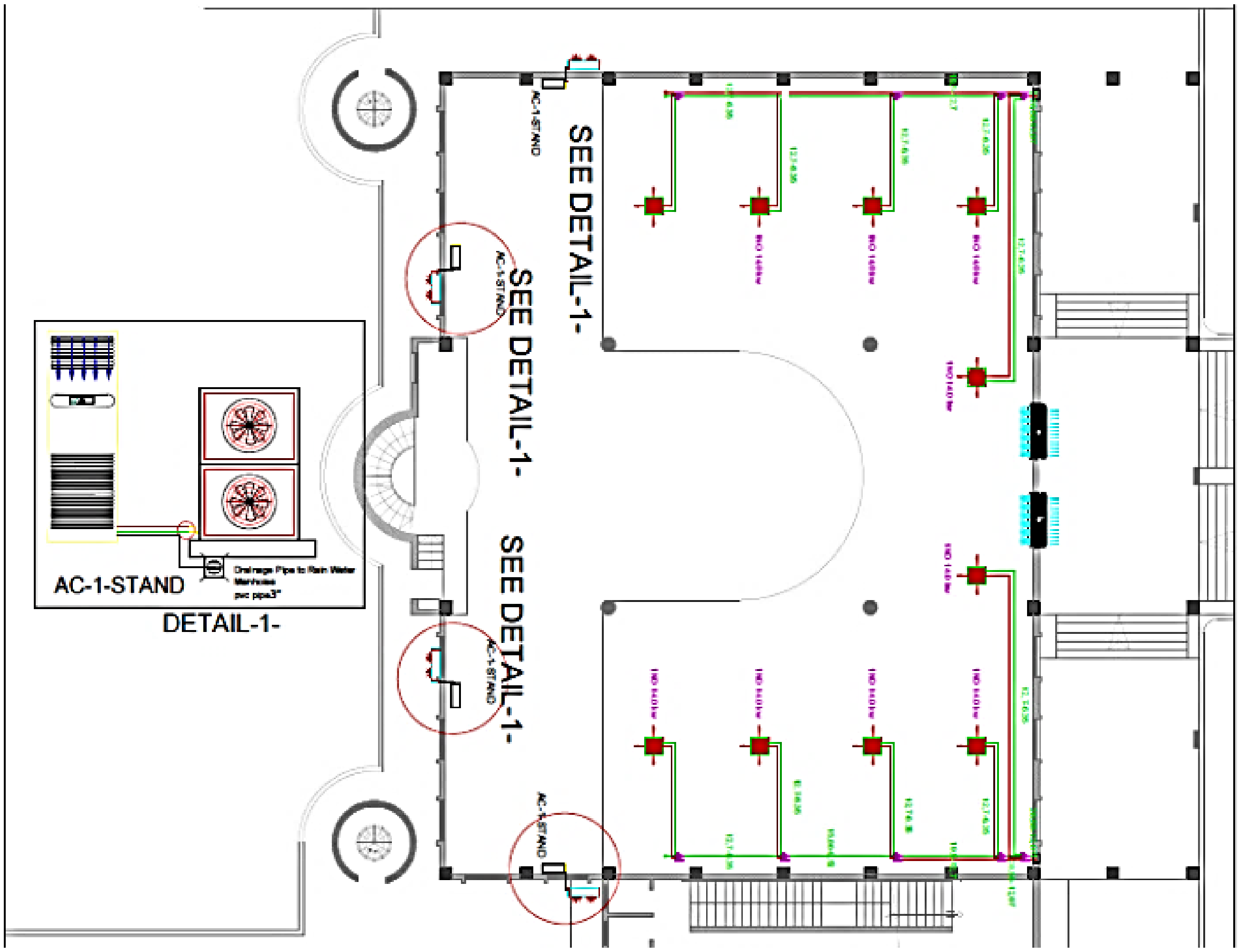

Figure 4. The electrical power plans of the accessories

Consequently, it can be dispensed of a big amount of electricity used for heating and the expensive bills of electricity. In addition, fossil fuels which is used for the generation of electrical power would be reduced significantly if this idea implemented on other building and mosques. Fossil fuel decreasing is very important for the environment as it results in CO2 emission increasing and emission of toxic gases.

5. Literature review

Al-Jubouri Omar Khalil, Al-Jubouri Ahmed Hassan [6] (Principles of Renewable Energies) The study includes many aspects related to the most important principles that can be relied upon and that are naturally and sustainably generated, and it includes energy as solar, which is the main source of energy on the surface of the earth in addition to wind and thermal energy, where the study included the most important The traditional energy sources used in the world currently and the global consumption rate, the study included definitions and how to calculate solar radiation falling on different surfaces through a set of mathematical models and studying the radiative properties of materials and solar radiation measurement systems, in addition to the various thermal applications of energy as solar in a simplified manner, as it included solar water heaters and heating and cooling systems based on energy as solar and water desalination. The study also included wind energy, which has begun to play a major role in generating electrical energy through wind turbines and determining the useful wind speed while providing a general mathematical analysis of wind energy.

The study by Bahabil, Muhammad bin Ali [7] includes the search for new energy resources that have low cost and are inaccessible, so that this alternative energy is environmentally friendly, has no negative impacts on the environment or on human health, and meets the world's increasing demands to reduce emissions of warm gases (house gas emission green) which is usually emitted from the use of traditional fuels, such as: petroleum and coal. This interest is confirmed in poor or low-income societies, which take energy and support services a large part of the per capita income. The study covered energy as solar, wind energy, geothermal energy, cooling towers, and water recycling as an alternative to conventional energy.

The researchers in [8, 9], have evaluated the economic installing renewable implications source (PV cells) on a rooftop mosque in (KSA). The results revealed that the annual mosque bill might be minimized to almost 0 under mechanism of net metering. The researchers in [8], introduced the application of energy as solar to investigate the feasibility of using grid-connected solar system for electricity generation in mosque buildings. Software of PVsyst is utilized to detect the design being optimal for total load connected of 80 kW. According to study obtained results, the grid-connected (PV) development of solar system in Kuwait might be viable economically and providing shaving as peak throughout loads of peak.

The researchers in [10-12] examined the heating reaction of different kinds of base thermal schemes to leap-change plane temperatures between 40° C and 20° C utilizing 3 variables: firstly, is whole thermal exchanging between the pipe and the room at the top and bottom of the floor. Secondly, is the absorption of the heat starting from the pipe into the floor, and finally heat transfer relationship with the thermal consumption.

Meanwhile, the researchers in [13-15] studied the heating system by utilizing thermal transmittance amount of pipe output into temperature of the surface, in addition thermal admittance which consists of the surface outcome ratio into the temperature of surface. The distinction between the transmittance slope and the admittance slope is equivalent to the stored power quantity in the mass as thermal, and that lead us to facilitate the controllability of radiant systems an appropriate indicator.

Michal and Ondřej [16] examined a different measure of the thermal reaction of radiant cooling and warming cooling structures is called thermal storage efficiency. The efficiency of the heat storage was contrasted with the defined indicators described by the constant τ_{63}, response time τ_{95}, and the (TES) called thermal energy storage. The distinction was conducted for many wall cooling samples with diverse pipe position arrangements, material layer construction, and thermal core equipment. It was possible for comparing the thermal complicated systems performance by a sole value, taking into account the entire curve of response (HSE) in place of concentrating on a particular curve point (τ_{63}, τ_{95}). Stored thermal energy has anticipated the thermal reaction of some arrangements, but could not be appropriate for contrasting the thermal behavior of many thermal admittances with radiant systems. In addition, an innovative thermal output indicator named effective output as thermal (ETO) has also been explained.

Chikh [17] utilized temperature of room over shoot and time constant following a phase increase in the calibrated temperature point of room by one degree in a radiant heating floor room. A source of heat found in different depths inside the floor provided the heat output. The researchers in [18-20] expanded a simplistic computation example of the thermal characteristics of a heating blob taking into account different design factors. In comparison to the negligible pipe diameter and thermal conductivity effect, the water flow rate and the heat slab capacity greatly affected the time constant τ_{63}. According to Al-bayaty, et al. [21], the energy can be converted from state to a different and can be formulated in questions and designed in desired constructions as the mosque case study has been selected.

6. Methodology and numerical work

6.1.Geometry creation

The software program ANSYS Design Modular 2019 R3 has been used to draw the geometry which is shown in figure (5), this figure presents six sub figures illustrates the distribution of the layers on the floor. The dimensions for the geometry will be as the length and width of 20 by 20 meters and the tube diameter to be as 0.1 meters which is made from copper and the surface and ground are from different materials which will be shown later with their properties. The distance between each and every tube is to be one meter.

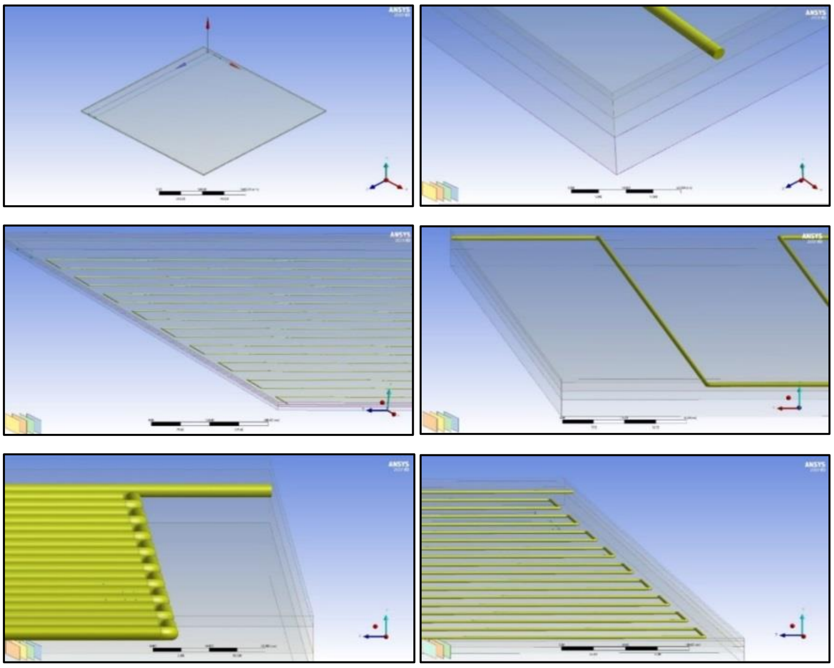

Figure 5. The Geometry model in the design modular

6.2.Meshing strategy

The second step will be the geometry meshing in which all the bodies being meshed to generate the grids in which the governing equations should be solved. The Ansys mesher has been used to generate the mesh and it is done by selecting some body sizing and methods that are capable of generating good quality mesh. After the mesh has been completed, the total number of the generated cells was around 1,704,191 elements and with both kind of hexahedral and tetrahedral mesh which is shown in figure (6). After that the geometry has to be given the boundary names or what is called the name selection to allow the solver to automatically know the appropriate boundary conditions that are needed. For this, we called the faces to be, inlet to the tubes and outlet from the tubes and other faces are walls with different boundary conditions.

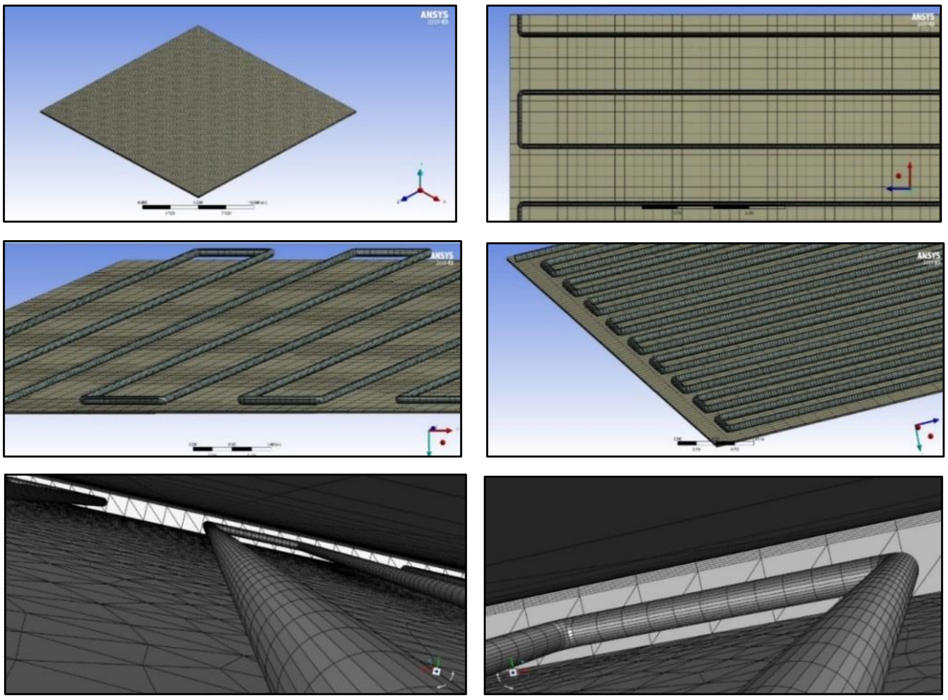

Figure 6. The Meshing of the whole model

7. ANSYS Fluent Solver

The model is now complete and ready to be read into Fluent which is the solver from Ansys, the system of the equations that will be solved automatically by the solver will be discussed below. The steady state is chosen to solve the differential equations and with the pressure-based solver and by enabling the energy equation inside the solver panel. The fluid flow which is water and the flow is considered to be turbulent as Reynold's number is greater than 2500 and hence, the RNG K-epsilon model has been adopted for the turbulent flow from the viscous model panel. The materials that are used are as follows: fluid is water with the following properties,

$$density\ \rho = 998.2\frac{kg}{m^3}\ ,specific\ heat\ \ Cp = 4182\frac{J}{kg.\ K}\ ,thermal\ conductivity$$

$k = 0.6\frac{W}{m.\ K}$ $,viscousity\ \mu = 0.001003\ Pa.s,$ and for the solids we considered the following materials: Copper with the properties, $density\ \rho = 8978\ \frac{kg}{m^3},$

$specific\ heat\ \ Cp = 381\frac{J}{kg.\ K}\ ,thermal\ conductivity\ k = 387.6\frac{W}{m.\ K},$

Ceramic with the properties, $density\ \rho = 2650\ \frac{kg}{m^3},$

$specific\ \ heat\ \ Cp = 900\frac{J}{kg.\ K}\ ,thermal\ \ conductivity\ k = 0.17\frac{W}{m.\ K},$

Cement with the properties, $density\ \rho = 1440\ \frac{kg}{m^3},$

$specific\ \ heat\ \ Cp = 920\frac{J}{kg.\ K}\ ,thermal\ conductivity\ k = 1.7\frac{W}{m.\ K}$, PVC with the properties, $density\ \rho = 1450\ \frac{kg}{m^3}\ ,specific\ heat\ \ Cp = 870\frac{J}{kg.\ K}\ ,\ \ thermal\ \ conductivity\ k = 0.19\frac{W}{m.\ K}$

Now the boundary conditions that are adopted are the velocity inlet which is calculated from the inlet flow rate that is taken as 840 L/h, for this and with the cross-sectional area of the tube, the inlet velocity is 0.029 m/s with inlet temperature of 40 ^{o}C, hence, the Reynold's number was calculated to be 2970 which indicates the turbulent flow.

7.1.Governing Equations

The governing equations of the solution will be the continuity equation and the momentum Navier-Stokes equations all together with the energy and k-e equations which is shown below:

A. Continuity equation

$$\nabla \cdot (\rho v^{\rightarrow}) = 0\ \rightarrow\ \frac{\partial_u}{\partial x} + \frac{\partial_v}{\partial y} + \frac{\partial_w}{\partial z} = 0 \qquad (1)$$

B. Continuity equation

$$\rho(u_x\frac{\partial u_x}{\partial x} + u_y\frac{\partial u_x}{\partial y} + u_z\frac{\partial u_x}{\partial z}) = -(\frac{\partial \tau_{x,x}}{\partial x} + \frac{\partial \tau_{y,x}}{\partial y} + \frac{\partial \tau_{z,x}}{\partial z}) - \frac{\partial P}{\partial x} + \rho g_x \qquad (2)$$

$$\rho(u_x\frac{\partial u_y}{\partial x} + u_y\frac{\partial u_y}{\partial y} + u_z\frac{\partial u_y}{\partial z}) = -(\frac{\partial \tau_{x,y}}{\partial x} + \frac{\partial \tau_{y,y}}{\partial y} + \frac{\partial \tau_{z,y}}{\partial z}) - \frac{\partial P}{\partial y} + \rho g_y \qquad (3)$$

$$\rho(u_x\frac{\partial u_z}{\partial x} + u_y\frac{\partial u_z}{\partial y} + u_z\frac{\partial u_z}{\partial z}) = -(\frac{\partial \tau_{x,z}}{\partial x} + \frac{\partial \tau_{y,z}}{\partial y} + \frac{\partial \tau_{z,z}}{\partial z}) - \frac{\partial P}{\partial z} + \rho g_z \qquad (4)$$

C. Energy equation

$$\nabla \cdot (v^{\rightarrow}(\rho E + p) = \nabla \cdot (k_{eff} \nabla T - h j^{\rightarrow} + (\mu[(\nabla v^{\rightarrow} + \nabla v^{\rightarrow T}) - \frac{2}{3} \nabla \cdot v^{\rightarrow} I] \cdot v^{\rightarrow})) \quad (5)$$

D. K-epsilon equations

$$\frac{\partial}{\partial x_i}(\rho k u_i) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\delta_k}\right)\frac{\partial k}{\partial x_j}\right] + G_k + G_b - \rho\varepsilon - Y_M \quad (6)$$

$$\frac{\partial}{\partial x_i}(\rho \varepsilon u_i) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\delta_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_j}\right] + C_{1\varepsilon}\frac{\varepsilon}{k}(G_k + C_{3\varepsilon}G_b) - C_{2\varepsilon}\rho\frac{\varepsilon^2}{k} \quad (7)$$

8. Results

A. Velocity Vs Tube Length

Figure (7-A) below, shows the velocity distribution along the tube length, it is shown that the velocity is developing inside the tube as it moves along the tube. The flow is not developed at the inlet due to the entrance region effects and after some distance, it gets more developed until the full development region. This distribution is taken along a line fitted at the center of the tube and along its length. The figure shows the distribution of velocity for all the tubes.

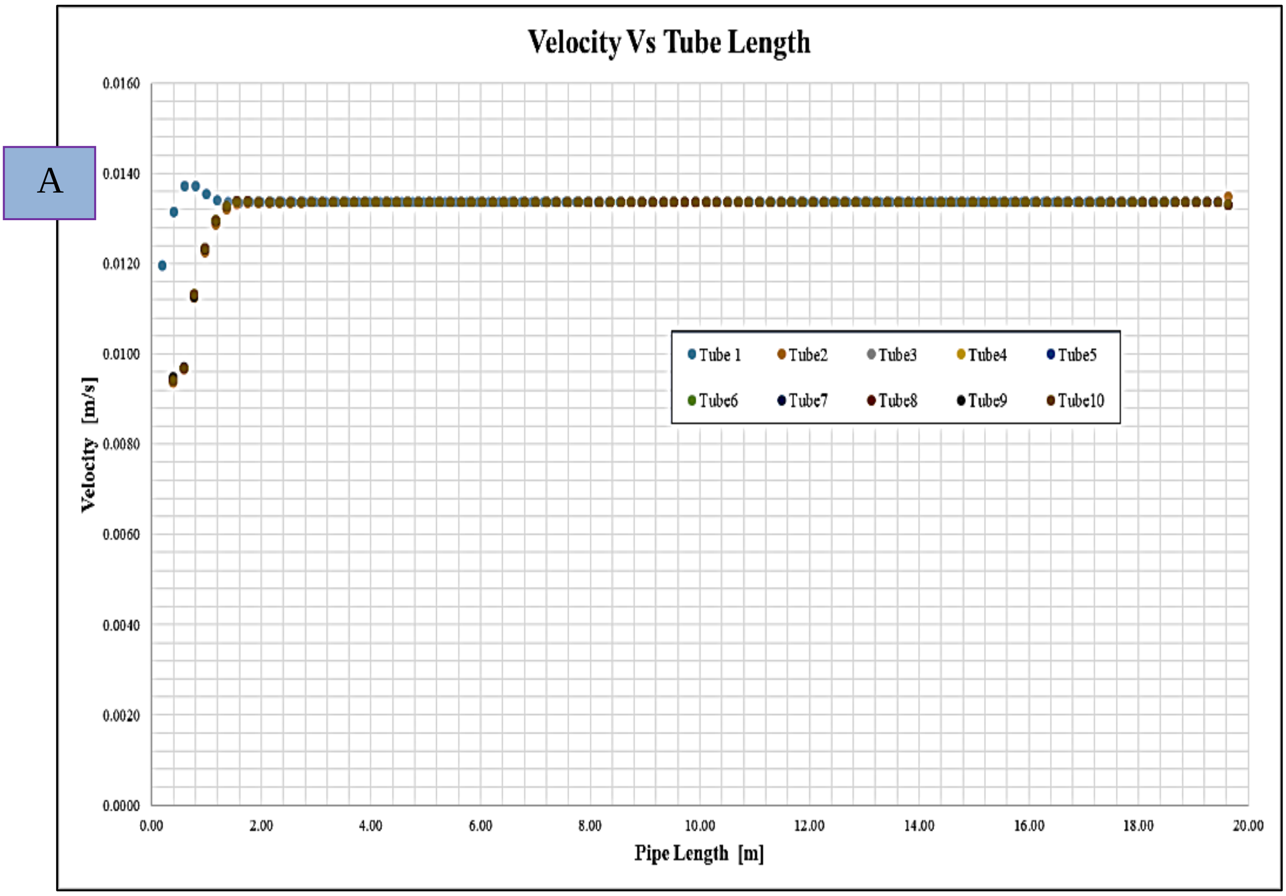

Figure 7-A. Velocity inside Tubes

Figure (7-B) shown below, illustrates the streamline of velocity distribution along the tube length, the flow velocity is getting increased due to the sudden turn which decrease the pressure, and the maximum velocity is calculated to be 0.044 m/s. This figure is for the first tube burred inside of the ground.

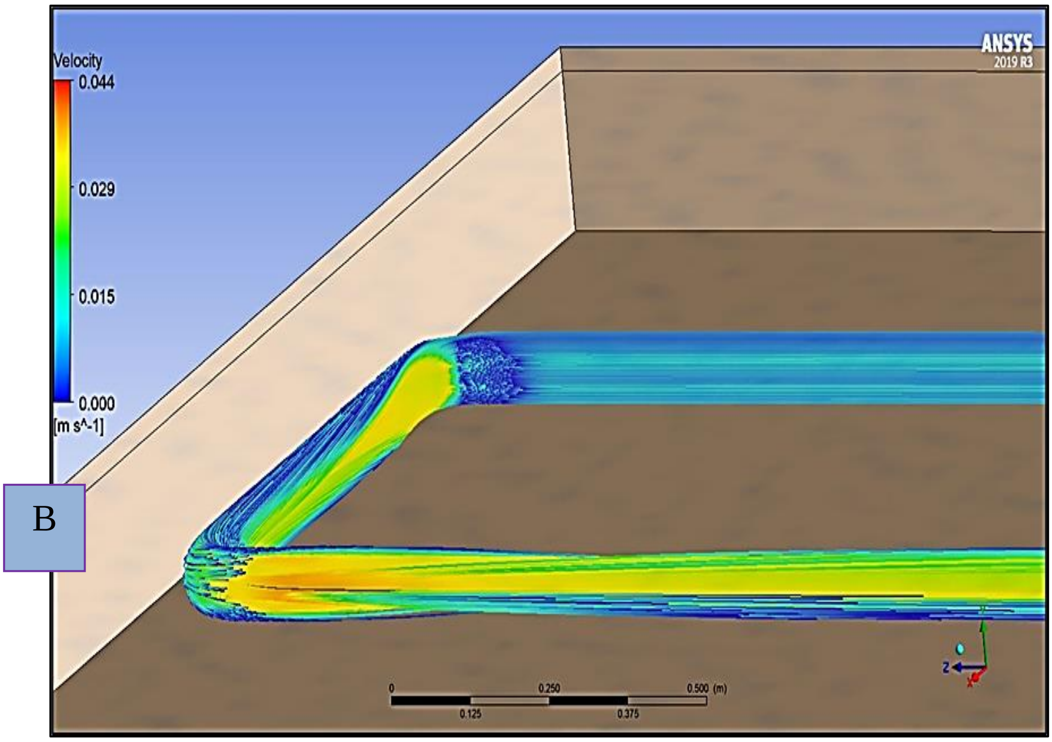

Figure 7- B. Streamlines inside Tubes Length

B. Temperature Vs Tube Length

Figure (8-A) Shows temperature distribution of the flow along all the tubes center lines. The flow temperature is getting decreased from the inlet towards the end of the tube and that trend applies to all tubes. Water enters at the first tube with its maximum temperature value of 314K then it is decreased along each tube's length and each tube until it reaches the outlet of the last tube.

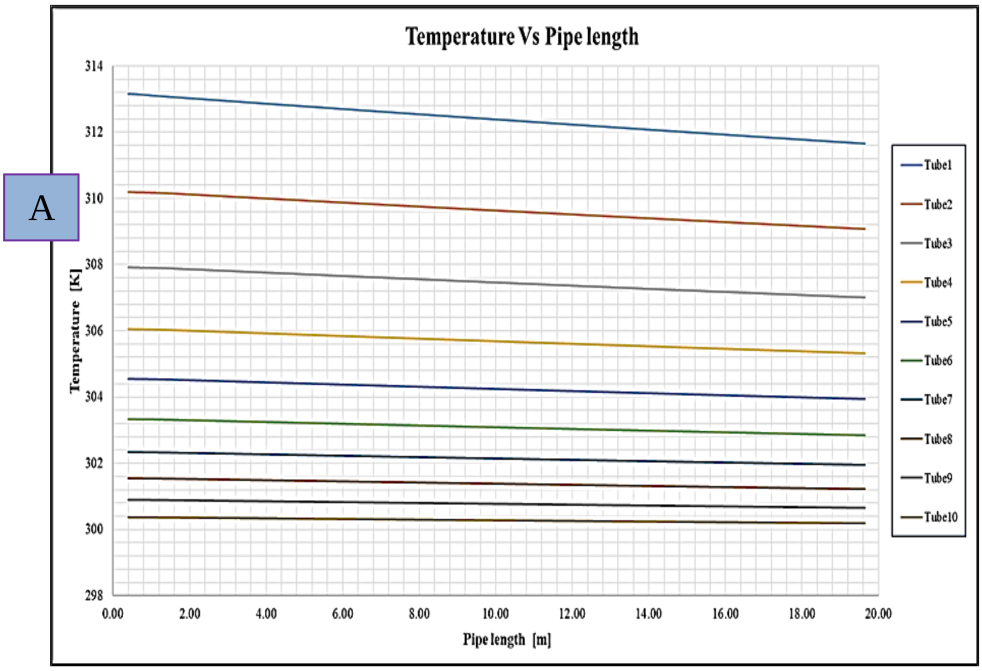

Figure 8-A. Temperature Vs Tube Length

This decreasing of the temperature is due to convection in the fluid inside the tube and the conduction from the tubes surface towards the adjacent cells of the ground, hence; this will make the ground getting more heated.

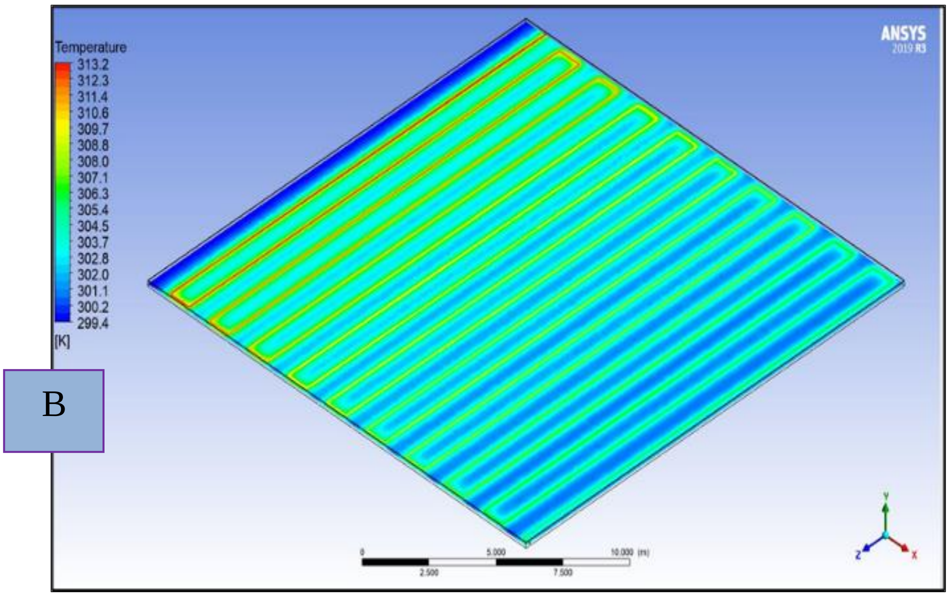

Figure 8-B. Temperature on mid-Plane

Figures (8-B) and (8-C) Show the temperature distribution along a plane at the center of the tubes and the temperature distribution on the surface of all the tubes, respectively. Both the figures show /that the temperature getting decreased and the flow getting cooled down, that will raise the ground temperature.

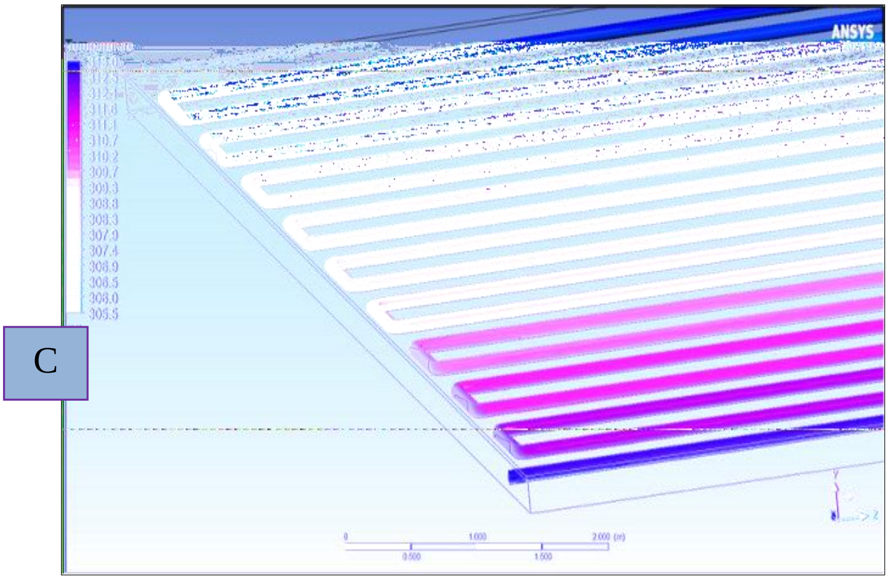

Figure 8- C. Temperature on Tubes Surface

Figure (8-C) Shows that the temperature distribution along the tube is getting decreased from the inlet towards the end of the tube. The temperature enters from the first tube and it is at its maximum value which is around 314K and then it is decreased along each tube's length and at each tube until it reaches the outlet from the last tube. This decreasing of the temperature is due to convection in the fluid inside the tube and due to the conduction from the tubes surface towards the adjacent cells of the ground then this will make the ground getting more heated.

A. Pressure Vs Tube Length

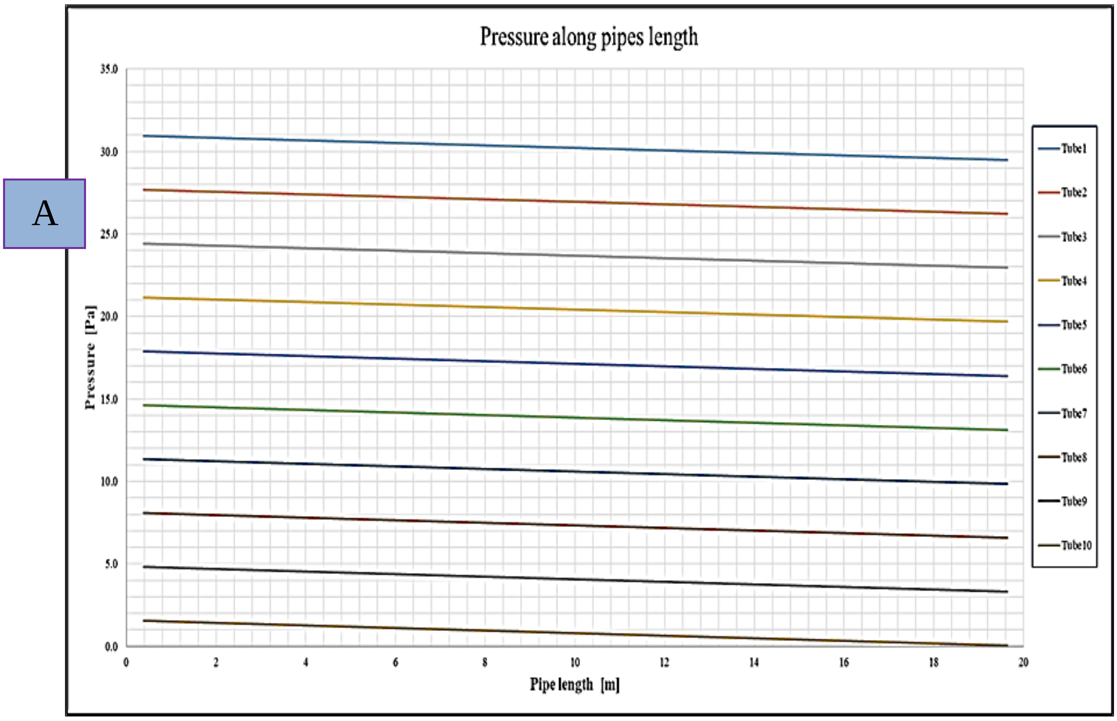

Figure 9-A. shows pressure vs. tube length

Figures (9-A) and (9-B) indicate the pressure along the tube for all the tubes and it shows that the pressure is getting decreased along each tube's length and for the other tubes until the outlet. The pressure drop is noticed for all the tubes and that is due to the drops that occur at the return for each tube and because of the many number of returns in the tubes until the end, the fluid flow will encounter a pressure drop and it starts from around 30 Kpa and reaches zero which represents the atmospheric pressure.

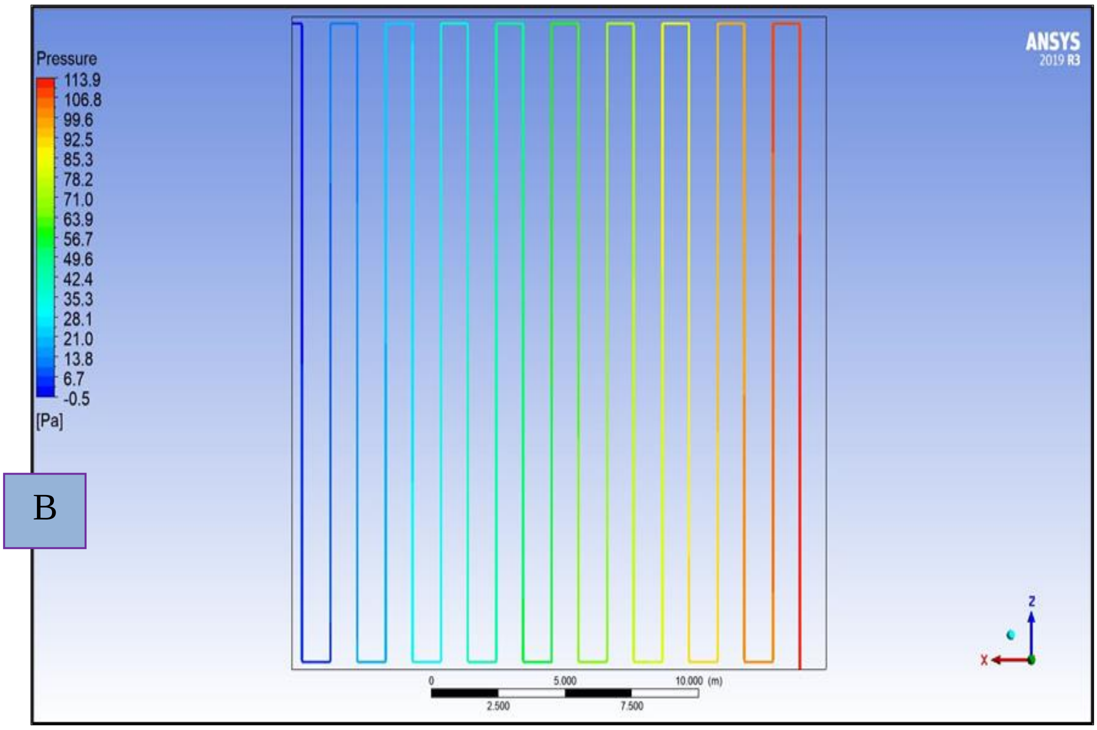

Figure 9-B. Pressure contour inside tubes

Radial velocity vs tube diameter

Figure10 below, describes is the radial velocity along tube diameter at some distances from the inlet which indicates the distance at which the fully developed occurs.

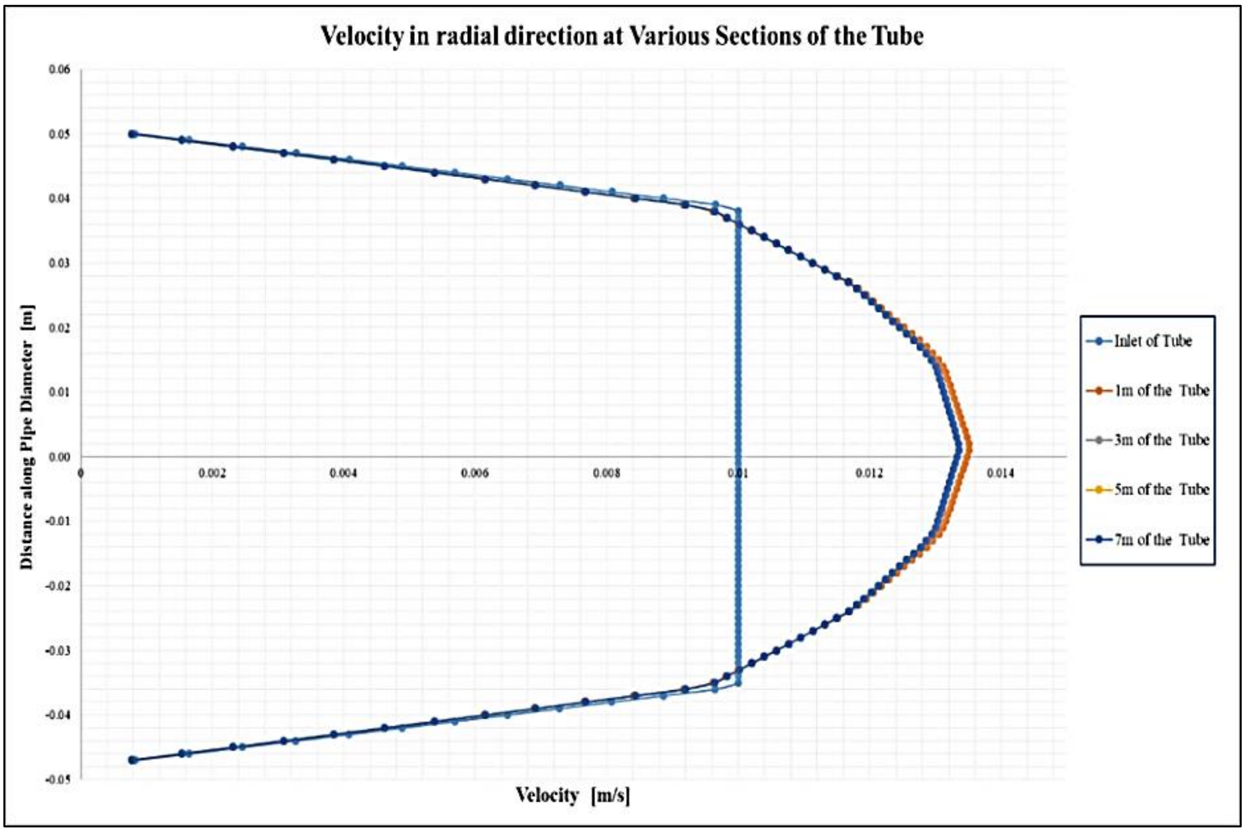

Figure 10. Radial velocity at tube diameter

9. Electrical power saving

The electrical calculation results show that the electrical energy consumed for heating a large distance needs 10 units, each unit spend 14 KW plus the water heating tanks for the winter period which necessary for the abolition and prayer. It makes sense if we considered daily 10 hours operation for the heating equipment for five times prayer plus weekly Friday prayers. If counted a normal month as 30 days in average, then the total monthly energy consumption would be 43500 Kwh multiplied by 120 units (according to official bills taken from the ministry of electricity). This number should be multiplied by 8 months at least as the city of Sulaimaniya (as a case study) is located at a cold region (the northern of Iraq) and needs longer time heating. From the aforementioned data it can be concluded that the money which can be invested from the implementation of this project is more than 34800 US dollars which equals to nearly 43 million Iraqi dinars.

10. Conclusion

This paper worked on the ability to use renewable energy and heat transfer idea in heating purposes using a novel design of a mosque building. Simulation of ANSYS as software program has been utilized for investigating actual building design with actual dimensions. The idea of investing the internal building space and tests conducting utilizing energy as solar to provide the energy required via the building, may reduce the electricity consumption and in result will reduce the emission of CO_2. Consequently, it may decrease the cost of the electricity. The effectiveness of this concept has been proved at the end of this work from analyzing the results. The results show that the total monthly energy consumption is 43500 Kwh which means that the total required bills would be 34800 US dollar. That means, it can cover the capital installation cost in only one year due to the great bills of electricity in Iraq and the maintaining capability of energy as solar.

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The authors are very thankful to everybody helps in collecting the real data regarding the design of the Mosque located in Sulaimaniyah city in the north of Iraq.

Accessibility of material and data
The datasets produced throughout and/or analysed throughout the undertaking study are obtainable from the author of correspondence on rational demand.

Authors' contributions
Haseeb and Al-bayaty conceived of the presented idea. Haseeb developed the theory and performed the computations. Abdulkarim, worked on the simulation program and verified the analytical methods. Al-bayaty has encouraged Haseeb to investigate the architecture design of the case study and supervised the findings of this work. All authors discussed the results and contributed to the final manuscript.

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