# MULTI-YEAR OPERATION EFFECT OF GEOTHERMAL HEAT EXCHANGER ON SOIL TEMPERATURE FOR UNT ZERO ENERGY LAB

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Ground source heat pump (GSHP) uses earth's heat to heat or cool space. Absorbing heat from earth or rejecting heat to the earth, changes soil's constant temperature over the multiple years. In this report we have studied about Soil temperature change over multiple years due to Ground loop heat exchanger (GLHE) for Zero Energy Research Laboratory (ZØE) which is located in Discovery Park, University of North Texas, Denton, TX. We did 2D thermal analysis GLHP at particular Depth. For simulation we have used ANSYS workbench for pre-processing and FLUENT ANYS as solver.

TAC Vista is software that monitors and controls various systems in ZØE. It also monitors temperature of water inlet/outlet of GLHE. For Monitoring Ground temperatures at various depths we have thermocouples installed till 8ft from earth surface, these temperatures are measured using LabVIEW. From TAC Vista and LabVIEW Reading's we have studied five parameters in this report using FLUENT ANSYS, they are; (1) Effect of Time on soil Temperature change over Multi-years, (2) Effect of Load on soil temperature change over Multi-years, (3) Effect of Depth on soil temperature change over Multi-years, (4) Effect of Doubling ΔT of inlet and outlet of GLHE on soil temperature change over multi-years and (5) Effect on soil temperature change for same ZØE Laboratory, if it's in Miami, Florida.

For studying effect of time on soil temperature change for multi-years, we have varied heating and cooling seasons. We have four cases they are Case A: GSHP always “ON” (1) 7 months cooling and 5 month cooling and (2) 257 days are cooling and 108 days heating. Case B: GSHP “OFF” for 2 months (1) 7 months cooling and 3 months heating and (2) 6 months cooling and 4 month heating. For Studying Effect of Load on soil temperature change over multi-years, we have considered maximum temperature difference between inlet and outlet for heating and cooling season for simulation. For studying effect of doubling ΔT of inlet and outlet of GLHE, we have doubled the temperature difference between inlet and outlet of GLHP. There will be soil temperature change over year at various depths. For studying Effect of Depth on soil temperature change for multi-years, we have consider 5 depths, they are 4ft, 6ft, 8ft, 110ft and 220ft. The Densities of soil are known from site survey report of ZØE GSHP manufacturers till depth of 13ft. For studying effect of soil temperature over multi-years for same ZØE in Miami, Florida, we have considered equivalent cooling and heating season from weather data for past one year and assuming same number of days of cooling and heating for next 20 years we have simulated for soil temperature change

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## NOMENCLATURE

| | |
|---|---|
| AHU | Air Handler Unit |
| GCHP | Ground Coupled Heat Pump |
| GLHE | Ground Loop Heat Exchanger |
| GSHP | Ground Source Heat Pump |
| GWHP | Ground Water Heat Pump |
| SWHP | Surface Water Heat Pump |
| VGSHP | Vertical Ground Source Heat Pump |
| WAHP | Water to Air Heat Pump |
| WWHP | Water to Water Heat Pump |
| ZØE | Zero Energy Research Laboratory |

# CHAPTER 1

# INTRODUCTION

According to EIA Report 2013, crude oil production has increased to 5.0 million barrels per day from 6.5 million barrels per day from 2008 to 2012. Similarly, natural gas consumption has mostly increased in industrial sector especially for electric power generation. Natural gas consumption is predicted to increase by 16%, from 6.5 trillion cubic feet per year to 7.8 trillion cubic feet per year from 2011 to 2025 [1]. On 20 August 2013, crude oil price is $104.96, which is expected to increase to $120 (14.32%) after 1 year [2]. Rapid increase in fossil fuel prices has brought boom for renewable energy.

Total production and consumption of renewable sources has increased from 2010 to 2011, but again decreased from 2011 to 2012. Total production of renewable energy increased to 8128 trillion BTU to 9170 trillion BTU from year 2010 to 2011. It decreased to 8867 trillion BTU in the year 2012. The total consumption was decreased from 9075 trillion BTU to 8825 trillion BTU from year 2011 to 2012. Like other states in the USA, Texas will be producing 5,880 MW of energy from renewable sources by 2018. In 2012, residential sector consumed 0.7 quadrillion BTU of renewable energy. In the residential sector, maximum energy is used for HVAC, therefore use of geothermal energy consumption has increased from 208 trillion BTU to 227 trillion BTU from 2010 to 2012.

Ground source heat pump (GSHP) uses earth's heat to heat or cool space. Absorbing heat from earth or rejecting heat to the earth changes soil's constant temperature over multiple years. Therefore, a study was conducted to measure soil temperature change caused by ground loop heat exchanger (GLHE) for multiple years for Zero Energy Research Laboratory (ZØE) which is located in Discovery Park, University of North Texas, Denton, TX. Study was based on simulating 2D thermal analysis of GLHP at various depths. For simulation ANSYS workbench and FLUENT ANSYS was used for pre-processing, solving and post processing.

TAC Vista is software that monitors and controls various systems in ZØE. It also monitors temperature of water inlet/outlet of GLHE. Thermocouples installed inside ground helps to monitor soil temperature at various depths. These thermocouples are monitored using LabVIEW software. From TAC Vista and LabVIEW reading's five parameters were studied in this report using FLUENT ANSYS. They are (1) effect of time on soil temperature change over multi-years; (2) effect of load on soil temperature change over multi-years; (3) effect of depth on soil temperature change over multi-years; (4) effect of doubling ΔT of inlet and outlet of GLHE on soil temperature change over multi-years; and (5) effect on soil temperature change for same ZØE laboratory, if it's in Miami, Florida.

For studying effect of time on soil temperature change for multi-years, heating and cooling season were varied. Case A: GSHP always "ON" (1) 7 months cooling and 5 month cooling and (2) 257 days are cooling and 108 days heating. Case B: GSHP "OFF" for 2 months (1) 7 months cooling and 3 months heating and (2) 6 months cooling and 4 month heating. For Studying Effect of Load on soil temperature change over multi-years, we have considered maximum temperature difference between inlet and outlet for heating and cooling season for simulation. For studying effect of doubling ΔT of inlet and outlet of GLHE, temperature difference between inlet and outlet of GLHE was doubled. There will be soil temperature change over year at various depths. For studying effect of depth on soil temperature change for multi-years, five cases at depth of 4ft, 6ft, 8ft, 110ft and 220ft was considered. The densities of soil are known from site survey report of ZØE GSHP manufacturers till depth of 13ft. For studying effect of soil temperature over multi-years for same ZØE in Miami, Florida, number of equivalent cooling and heating season was considered from weather data of past one year and assuming same data for cooling and heating season for next 20 years, a simulation was conducted for soil temperature change.

## 1.2 Thesis Structure

Chapter 1 deals with current energy production and consumption status in USA. It also explains about current renewable and geothermal energy status. To carry out this research a literature survey was done, this chapter explains about literature survey at the end. Chapter 2 explains about why this research topic was chosen for research. It also explains basic principle working of ground source heat pump, their various types and advantages. This research was carried on in Zero Energy Research Laboratory (ZØE) in University of North Texas, TX. Various characteristic features of ZØE are discussed in this chapter.

Chapter 3 deals with aim and problem statement of research. It defines clear cut aim and about 5 problem statement study that has to be conducted during research.

Chapter 4, ZØE's HVAC system works on GSHP, this chapter explains about VGSHP, WWHP and WWAH. It also gives brief explanation of principle working of ZØE's HVAC system.

Chapter 5, Methodology explains about method carried out to conduct research. It also give details about parameters such as inlet and outlet water temperature, density at various depths, temperatures for effect of time, effect of load and doubling ΔT of GLHE, effect of depth and soil temperature change for same ZØE in Miami, Florida for heating and cooling seasons.

Chapter 6 result and discussion is subdivided into five section to explain about effect of various time periods of heating and cooling on ZØE soil temperature over 20 years, effect of load on soil temperature change after 20 years, effect of various depth on soil temperature change after 20 year, effect of doubling load on soil temperature change and effect on soil temperature change if same ZØE building exists in Miami, Florida.

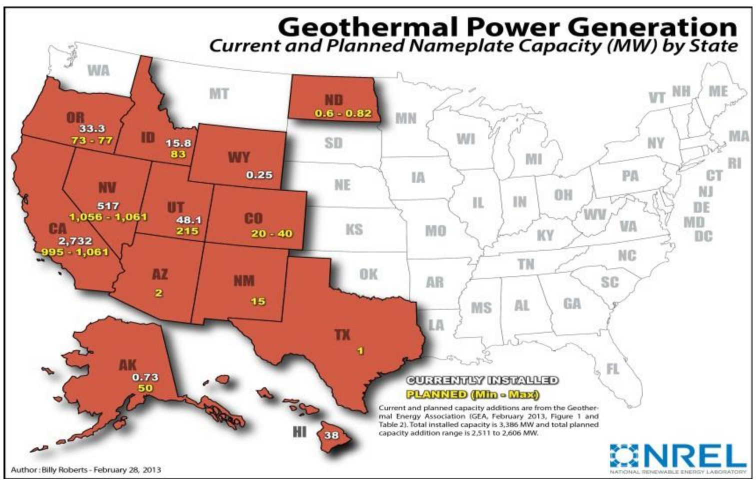
Chapter 7 explains conclusion of this research.

CHAPTER 2

BACKGROUND

## 2.1 Motivation behind This Research

In United States from April 2012 to April 2013 geothermal energy generated was 16.9 million megawatts-hours. In USA 15 billion kw-hrs of geothermal power is produced every year, which is the equivalent of burning 6 million tons of coal and 25 million barrel of oil for generation of power [7]. Currently California generates 80.7% of total geothermal power in US, followed by Nevada and Utah (Figure 1) [7].

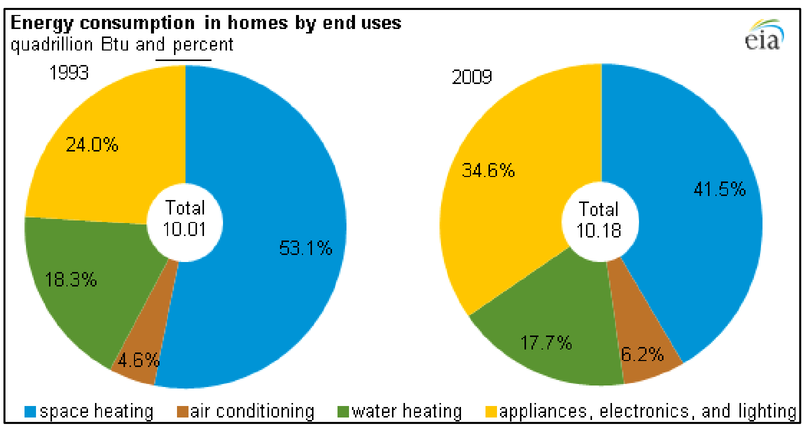



Source: http://en.wikipedia.org/wiki/Geothermal_energy_in_the_United_States

Figure 1: Geothermal Power Generation Current and Planned Capacity by State

Generally, 47.7% of total energy consumption in homes is consumed for space heating and air conditioning, which covers maximum part of energy consumed in homes (Figure 2). Geothermal energy is one of the best options to save this energy consumed from HVAC for residential and commercial buildings. Geothermal energy is in demand because it’s a renewable source of energy, clean operation, low maintenance, Low effective cost and low carbon dioxide emission compared to other space conditioning equipments [8].

GSHP has GLHE which absorbs or rejects heat from ground to heat or cool space. Continues absorbing or rejection heat by GLHE for longer period changes temperature of soil. Continues heat addition to soil during longer cooling season will heat up soil, which increases temperature of soil. Due to shorter heating season, some amount of heat will be carried to next year's cooling season. Thus, GSHP will require more amount of work to cool additional heat. Same thing keep on happening for multiple years, which affects GSHP's performance. In this respect, a project has been carried out to study the effect of time, load and depth on soil temperature change after 20 years for GSHP at Zero Energy Lab located at University of North Texas, Denton, TX.




Source: U.S. Energy Information administration, Residential Energy Consumption Survey

Note: Amounts represent the energy consumption in occupied primary housing units.

Figure 2: Energy Consumption in Homes Compared with 1993 and 2009

## 2.2 Ground Source Heat Pump, Types and Uses

### 2.2.1 Ground Source Heat Pump Working

Ground source heat pump is heat pump which takes heat from earth in winter (act as source) and rejects heat to earth in summer (act as sink). First ground source heat pump was built by Robert C. Webber in late 1940. First successful commercial ground source heat pump was built 1946 in commonwealth building in Portland, Oregon [3]. Approximately, 17% of sunlight is reflected by cloud, 4% is absorbed by clouds, 19% is absorbed by water vapor and dust, 6% is reflected by ground surface and 46% of sunlight is absorbed by ground. Absorbed sunlight warms ground, thus temperature of ground remains almost constant throughout the year. Heat pump absorbs this low grade heat from earth and releases this heat at useful location for space heating/cooling or water heating. Arrangement of ground array for ground source heat pump can be done in horizontal, vertical or inclined (Figure 3) [4].

Source: http://ashgrove.ie/product_view.php?id=33&move=1&cat_id=2

Figure 3: Ground Array for Geothermal Heat Pump

Main components of ground source heat pump are energy absorbing pipes installed in the ground called ground array or ground loop heat exchangers, compressors and expansion valve (Figure 4). The complete system is divided into three subsystems: (1) an earth connection subsystem; (2) heat pump subsystem; and (3) heat distribution subsystem [6]. Water with antifreeze mix is pumped though ground array. Water passing through ground array is constantly warmed by ground low grade heat. Warmed circulated water is then fed into heat exchanger called evaporator. On secondary side of evaporator is refrigerant, which is working fluid. Refrigerant absorbs heat from warmed circulated water from ground array. After absorbing heat, refrigerant starts to boil and turn into gas. It is then fed to compressor, where due to rise in pressure, temperature of refrigerant increases. Hot refrigerant is fed to condenser. In condenser, refrigerant's heat is released; this heat is absorbed by pipes containing water for space heating or water heating. After condenser, hot liquid refrigerant pass through expansion valve to reduce its pressure and temperature. Refrigerant is then fed to Evaporator to repeat the cycle. In winter season, the cycle reverses [5].

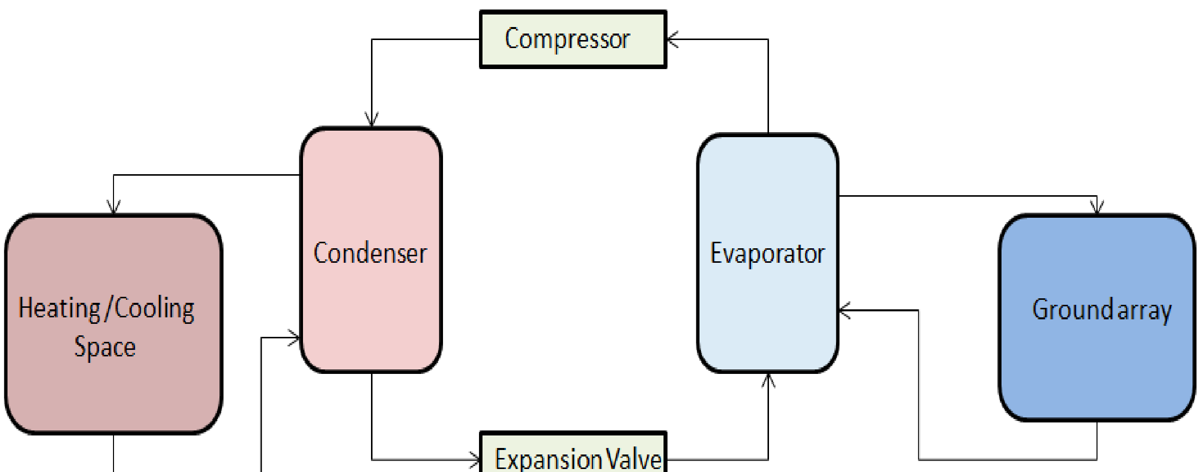
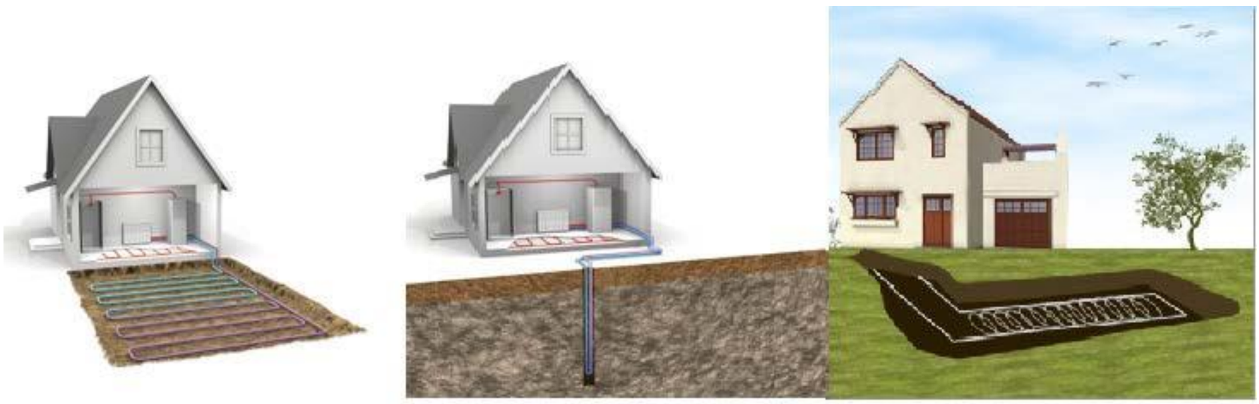



Figure 4: Geothermal Heat Pump Working

2.2.2 Ground Source Heat Pump Types

Basically there are three types of GSHP: They are (1) ground-coupled heat pump; (2) ground water heat pump; and (3) surface water heat pump.

Ground-coupled heat pump (GCHP) is buried closed loop pipes that extract heat or reject heat to soil. Basically, there are three kinds of GCHP (Figure 5). Horizontal GCHP have pipes placed in trenches horizontally (Figure 5(a)), main advantage of this arrangement is low installation cost compared to vertical GCHP. Vertical (Figure 5(b)) has pipes installed vertically to nearly 100-300ft below ground. Advantages of VGCHP are: 1) it requires less space with more surface area for heat exchange; and 2) stable soil temperature throughout year. Horizontal slinky GCHP have pipes coiled in spiral pattern and spread in dug pit (Figure 5(c)). Similar kind of pattern can also be done vertical way [9].



(a) (b) (c)

Source: (a) and (B) http://ashgrove.ie/product_view.php?id=33&move=1&cat_id=2

(c) http://www.egshpa.com/renewable-energy/geothermal-basics/geothermal-principle/geothermal-basics/

Figure 5: (a) Horizontal Ground-Coupled Heat Pump, (b) Vertical Ground-Coupled Heat Pump and (c) Horizontal Slinky Ground-Coupled Heat Pump

Ground water heat pump (GWHP) is open loop system which pumps water from ground water table. Water running through ground array absorbs heat. This heat is exchanged in heat pump and cold water is returned again to ground water table (Figure 6). It has lowest installation cost, especially for larger applications [9]. Surface water heat pump (SWHP) adds heat or rejects heat to surface water bodies. Direct SWHP have pipes immersed in water bodies, which carries water to heat pump. Indirect SWHP is done by coupling, which has special purpose pipes immersed in water bodies (Figure 7) [9].

Source: http://www.egshpa.com/renewable-energy/geothermal-basics/geothermal-principle/geothermal-basics/

Figure 6: Ground Water Heat Pump

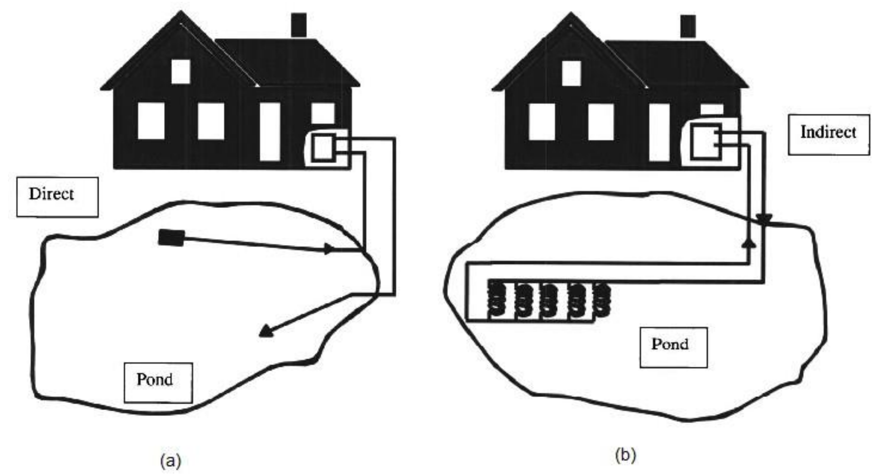



Figure 7: (a) Direct Surface Water Heat Pump (b) Indirect Surface Water Heat

2.2.3 Advantages of GSHP

Heat pumps are cheaper to run compare to direct electric heating, oil and gas boilers. GSHP cools space in summer and heat space in winter. As there is no combustion, so they are safe and require less maintenance. GSHP saves carbon emission [10]. GSHP draws or reject heat to earth, which is renewable source of energy. Using GSHP Lower fuel bills and saves money. They are quiet in operation.

2.3 Zero Energy Research Laboratory (ZØE), University of North Texas, Denton, TX

Zero Energy Research Laboratory at University of North Texas, Denton, TX was constructed in April 2012. ZØE is research intended building, which aims at energy production and saving in residential building. ZØE main purpose is to be net zero energy consumer, which means summation of energy production and consumption should be zero. Energy production systems in ZØE are photovoltaic and wind turbines. Geothermal energy is used for HVAC and water heating. Figure 8 and 9 shows front and right side top view of ZØE.

Figure 8: Front View of Zero Energy Research Laboratory (ZØE)

Figure 9: Right Side Top View of Zero Energy Research Laboratory (ZØE)

Systems in ZØE are vertical ground source heat pump, energy ventilation recovery, solar chimney, solar water heater, radiant floor. Other features of ZØE are bamboo flooring, leaving space (Figure 10), rainwater harvesting, Monitoring system and 90 control sensors. Table 1 shows various features of ZØE.

(a) (b)

Figure 10: inside ZØE in living room

Table 1: Features of ZØE

| **Characteristic** | **Value** |
|---|---|
| Floor area | 1200 sq.ft |
| Window-wall ratio | 33.56% |
| Net conditioned building area | 171.76 $m^2$ |
| Energy generation units | |
| Wind turbine | 5 blade, horizontal axis, 3.5 KW-rating, 500 kwh/month (average wind speed 5m/s) |
| Solar PV panels | 24 pieces of module, 5.64Kw capacity |

| | |
|---|---|
| HVAC | |
| Vertical GSHP | 6 wells, 225 ft deep, WWHP for cooling and heating, WAHP for cooling and heating, WWHP for hot water and energy recovery ventilation for pre-heat air. |
| Lightening | Halogen lights with daylight-detecting sensor, architecture design to utilize natural light. |
| Rainwater harvesting system | 3000 gal capacity, bio-filtration system, 5 micron sediment, carbon filter and sanitron UV filter. |

2.4 Literature Review

To evaluate soil temperature change over multi-year, a literature study was conducted. Temperature distributions in boreholes of vertical ground-coupled heat pump systems [14], 3 vertical GLHE in this case are placed at 30 m, 60 m and 90 m. this study was conducted for 48hrs to get soil temperature distribution with consideration of grout material. This case study was conducted at Turkey, which has summer temperature around 40° C and winter temperature -5° C. Mean temperature difference between inlet and outlet of GLHE is 3.48° C for cooling season (ZØE mean temp difference of inlet and outlet 3.5° C). Specifications of 2D simulation are U-tube diameter 40mm, 35mm shank spacing and 150 mm borehole diameter. With the above parameters a FEM simulation was done to see temperature distribution.

Comparison of 2D conduction models for vertical ground coupled heat exchanger [15] explains about comparison study of thermal performance for cross section and thermal performance for axial section of VGLHE using COMSOL. In this mesh independent study and time independent study was done to choose correct mesh size and correct time for transient analysis. After performing simulation there was excellent agreement with analytical and numerical simulation with standard deviation of 0.027° C.

Simulation of domestic ground source heat pump system using numerical borehole heat exchanger model [16] explains about important parameters to be considered during GLHE simulation. As GSHP off for some hours, therefore effect of dynamics of fluid though tubes and thermal mass of circulating fluid is important parameter considering design. In this paper, author has used 3D borehole heat exchanger model. A comparison study with 2D and 3D model was also performed using solver GEMS3D.

Numerical simulation on heat transfer performance of vertical U-tube with different material [17]. In this paper comparison study of vertical GLHE's heat transfer for two different fill materials was conducted using CFD for operation time of 8 hours. Conclusion of this paper is that there is not much temperature difference between two cases and CFD analysis is good as it simplifies process.

Simulation and experiment on thermal performance of U-vertical ground couple heat exchanger [18] explains about a simulation carried out at 20-30m depth with different soil density for 30 years, considering two different seasons every year. In a double season mode, heat balance was seen and after 5 year there was reduction in soil temperature by 6°C, after 13 years there will change in 35° C. This is not good for GSHP.

# CHAPTER 3

## AIM AND PROBLEM STATEMENT

The main aim of this research is to evaluate effect of soil temperature change caused due to long cooling or heating season. Because of continues addition or rejection of heat to soil, there is change in soil's constant temperature over the years. This affects the COP of GSHP. To analyze soil temperature change over 20 years, a study was conducted for 2D thermal analysis of GLHE at depth of 8ft for below parameters,

(1) Effect of time

(i) 7 months cooling – 5 months heating season

(ii) 7 months cooling – 3 months heating season (GSHP off for 2 months)

(iii) 6 months cooling- 4 months heating season (GSHP off for 2 months)

(iv) 257 days cooling – 108 days heating season (ZØE TAC VISTA Data)

(2) Effect of load

(3) Effect doubling ΔT of GLHE

(4) Other study deals with soil temperature change over 20 years at various depths. For this study, various depths are as follows.

(i) Effect at 4ft

(ii) Effect at 6ft

(iii) Effect at 8ft

(iv) Effect at 110ft

(v) Effect at 220ft

(5) A study was conducted to compare existence of same ZØE of Denton, TX in the city of Miami, Florida with same load. Miami has almost same maximum and minimum outdoor temperature like Denton, TX in cooling and heating season. Considering this as

one of the criteria's, a study was conducted for 2D analysis of GLHE at 8ft for its heating and cooling season. An equivalent day for heating and cooling was taken from weather data [13].

CHAPTER 4

GROUND SOURCE HEAT PUMP AT ZØE

## 4.1 Ground Loop Heat Exchanger of ZØE

ZØE has 6 bore-wells located at backside of ZØE's building (Figure 12). Bore-well has 1" diameter, 225ft deep and distance between two wells is 20ft (Figure 13). Bore-well are filled with grout mixed with water, whose thermal conductivity varies from 0.69-1.00 W/m-k (Figure 14). U-tube pipes are made of polyethylene. While installation, first borehole is dug then U-tubes are inserted in borehole and lastly boreholes are filled with grout.

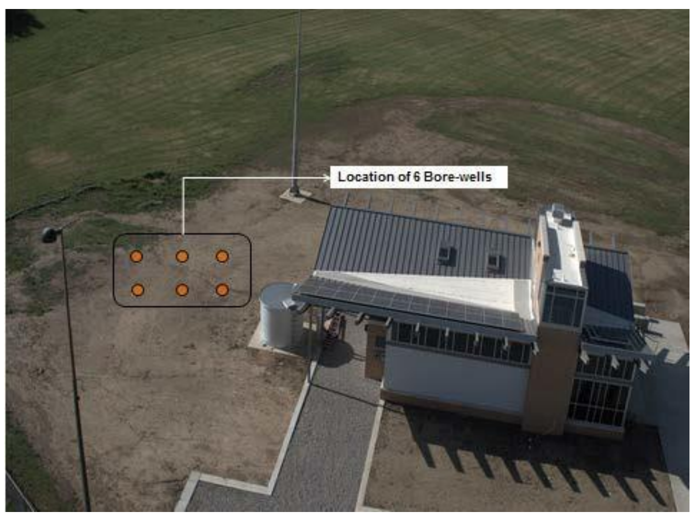



Figure 11: Location of Bore-Wells of ZØE

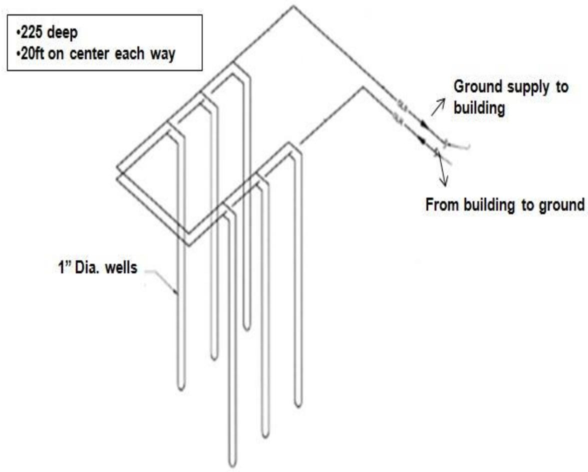



Figure 12: Ground Loop Heat Exchanger

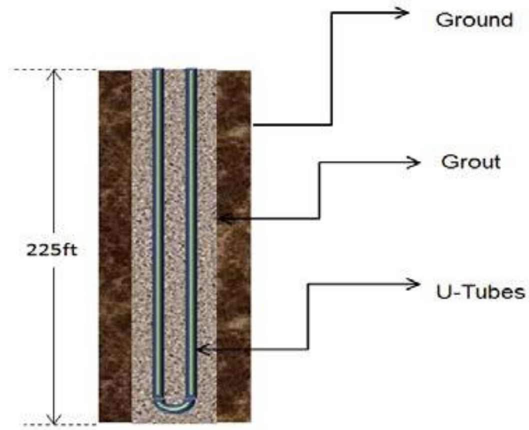



Figure 13: 2D View of Single GLHE

4.2 Water to Water Heat Pump (WWHP) and Radiant Floor:

On one end, Water to Water Heat pump (WWHP) is connected to GLHE which heats or cool refrigerant inside WWHP. On other end, WWHP is connected to Radiant floor. Refrigerant flowing through WWHP cools or heats water flowing through Radiant floor and thus space is cooled or heated by radiant floor. In ZØE radiant floor U-tubes are made of polyethylene material spread under the floor of ZØE (Figure 14). Table 2 gives description of WWHP.

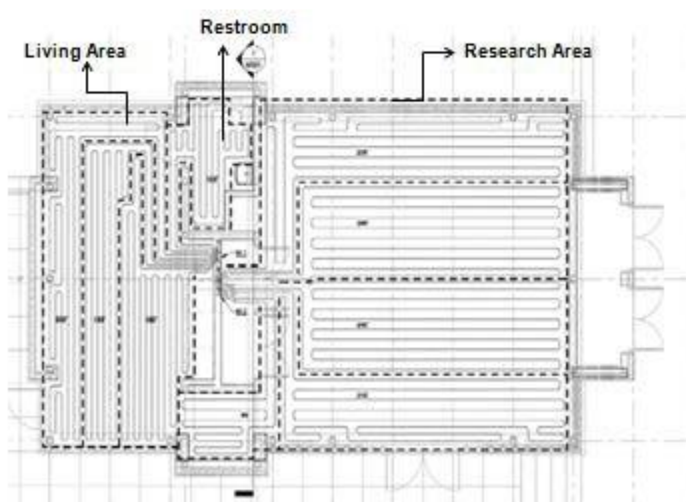



Figure 14: U-Tubes Arrangement of Radiant Floor of ZØE

Table 2: WWHP and Radiant Floor Characteristic Values

| Characteristics | | Value |
|---|---|---|
| WWHP | | |
| | Capacity | 1.792-2.32 Tons |
| | Refrigerant | R410A |
| Radiant floor | | |
| | Total length of tubes | 573 m |
| | Diameter of tubes | 0.0127 m |
| | U-tubes material | Polyethylene |
| | Thermal conductivity of tubes | 0.381 W/m-k |
| | Flow rate through tubes | 0.00671 $m^3/s$ |

4.3 Water to Air Heat Pump:

On one end, Water to Air Heat Pump (WAHP) is connected to GLHE and on other end it is connected to unit like Air Handler Unit (AHU). This unit helps to heats or cools air, conditions it and circulates in building. Figure 15 shows location of pipes blowing this conditioned air in ZØE.


Figure 15: Location of Air Supply in ZØE and Radiant Floor

Table 3: WAHP characteristics

| Characteristics | Value |
|---|---|
| WAHP | |
| Refrigerant | R-410A |
| Max flow rate | 1 $m^3$/sec |
| Rated cooling capacity | 7444 W |
| Rated heating capacity | 88264 W |
| Space temperature set-point | 75 F |

4.4 HVAC Systems Working

ZØE's heating, ventilating and air conditioning is carried out by WWHP and WAHP, vertical GLHE act as heat sink or heat source for both systems. ZØE system has radiant floor and unit like Air Handler.

Radiant floor uses radiant energy of hot or cold water and transfer it from heat or cold source to object [11]. Air handler is system which is used for conditioning and circulating air. In summers, air handler extracts hot air; exchanges heat with refrigerant and supplies cold and conditioned air to room [12].

In summer, VGLHP act as heat sink, cold water which output of VGLHP is fed to WWHP and WAHP and vice-versa in winter. WWHP is connected to radiant floor. Radiant energy of hot or cold water cools or heats space. Simultaneously, unit like Air Handler also heats or cools space by completing vapor compression cycle with WAHP.

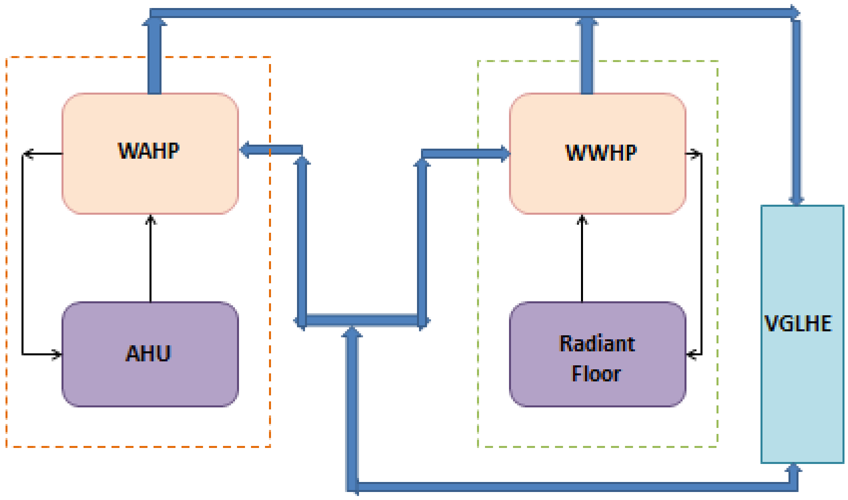



Figure 16: HVAC System of ZØE

CHAPTER 5

# METHODOLOGY

## 5.1 Theory

For this case of 2D geometry there is only conduction, for simple conduction for solid wall as boundary condition, energy equation is,

$$\frac{(\rho E)}{\partial t} + \nabla.\left(\overrightarrow{V}.(\rho E + p)\right) = \nabla.(k.\nabla T) \qquad \text{Equation 1}$$

For 2D Heat conduction and time dependent equation is

$$\frac{{}^{2}T}{x^2} + \frac{{}^{2}T}{y^2} = \frac{1}{\alpha}\frac{\partial T}{\partial t} \qquad \text{Equation 2}$$

## 5.2 Development of CFD Model

For 2D simulation of GLHE ANSYS 14.0 was used. First the geometry was drawn using ANSYS Design Modeler (Figure 17). Two different materials were considered while drawing geometry. Discretization of elements is one of important parameter in any of the simulation. During Meshing, fine meshing was applied surrounding inlet and outlet, also at the grout part. Figure 18 shows the meshing skill of geometry.

Table 4: Geometry Details

| **Characteristics** | **Values** |
|---|---|
| Geometry | |
| Grout diameter | 0.127 m |
| Inlet and outlet diameter | 0.0254 m |
| Length of soil part | 6.096 m |

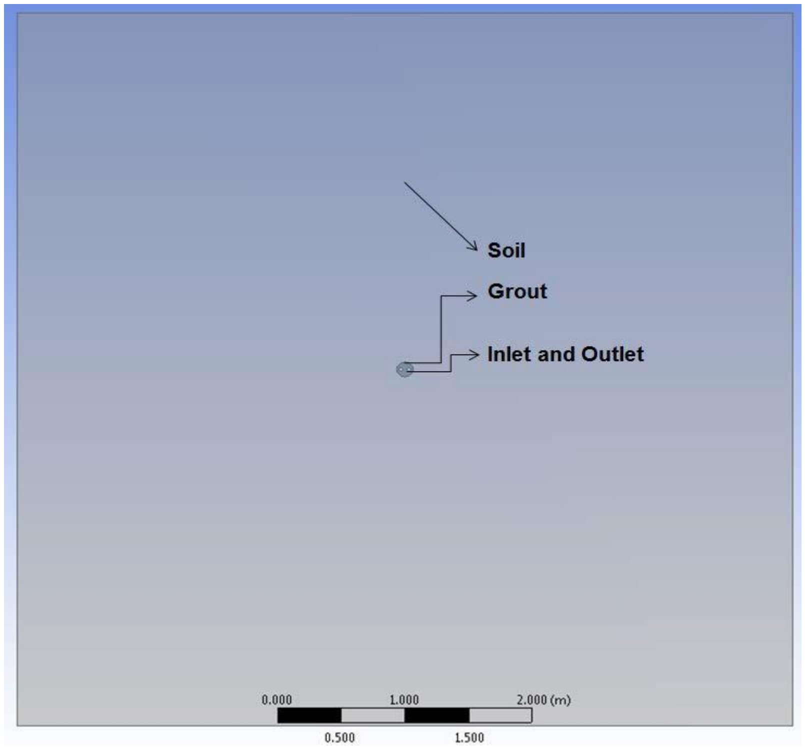



Figure 17: 2D Geometry of GLHE

Table 5: Meshing Details

| **Characteristics** | **Values** |
| --- | --- |
| Mesh nodes | 57299 |
| Mesh elements | 56875 |
| Mesh quality | |
| Average element quality | 0.945084 |
| Average aspect ratio | 0.99126 |

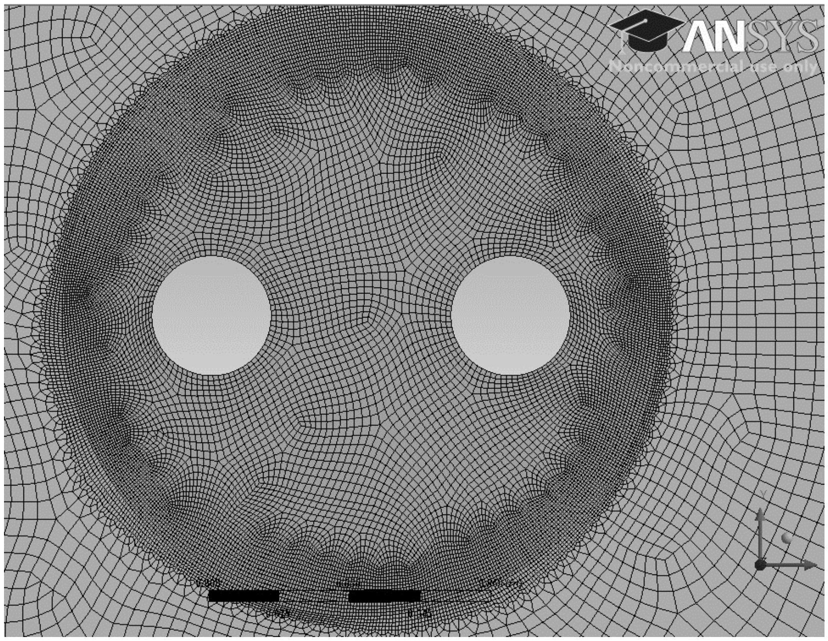


Figure 18: Meshing Skill

In simulation only one bore-well is considered. Simulation was carried out for 20 years. This simulation starts with first year's cooling season. Inlet and outlet temperatures of GLHE are known for first year's cooling season from TAC VISTA. Ground temperatures data was taken from thermocouple installed till 8 feet. Time step size was taken as 3600 sec and number of time-step were considered different for different type of simulation. For simulation of heating season of first year, with keeping same ground temperature, new values for inlet and outlet temperatures of GLHE were added in this transient simulation. Same procedure was followed for next 20 years simulation.

## 5.3 Material

Soil density varies at various depths. It varies till 100ft and remains constant further. As our main objective is to find soil temperatures change over multi-years, knowing soil density is one the important parameters. Figure 19 shows soil density till 13$^{th}$ feet depths for ZØE Denton, TX soil.

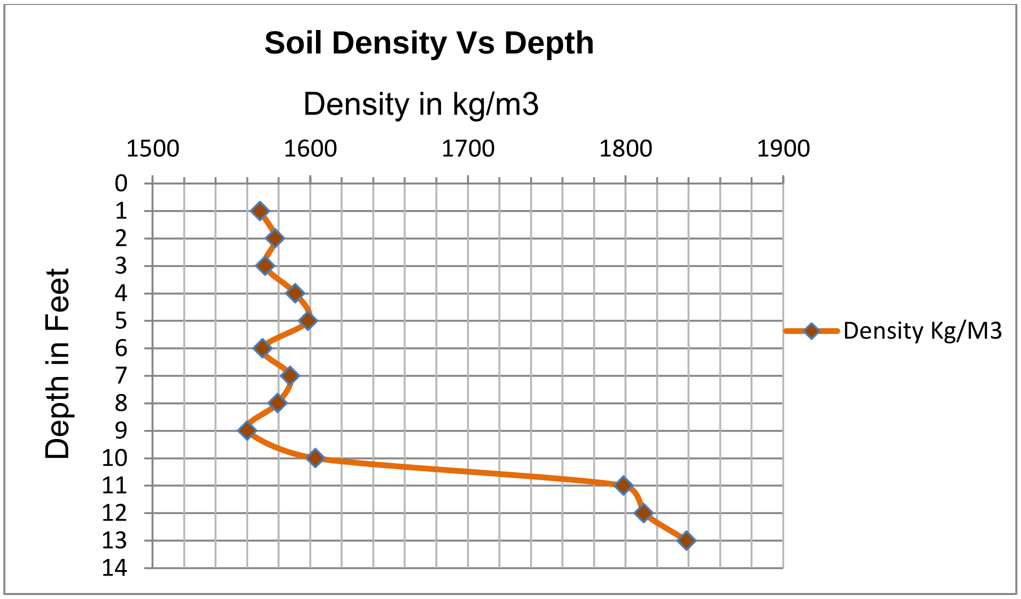



Figure 19: Soil Density vs. Depth for ZØE Soil

Thermal conductivities of materials like soil, polyethylene U-tube and grout are given in table 6.

Table 6: Thermal Conductivity

| **Thermal Conductivity** | **Value W/m-k** |
|---|---|
| Soil | 1.2 |
| Grout | 1 |
| Polyethylene U-tubes | 0.381 |

5.4 Effect of Time

5.4.1 Assumption

(1) Out of 6 boreholes, only one borehole is considered for simulations.

(2) Thermal conductivity of soil is constant throughout.

(3) 8ft depth was considered to get results of soil temperature change over multi-years.

(4) Maximum inlet water temperature from last one year's TAC VISTA reading was considered for simulation for cooling season.

(5) Minimum inlet water temperature from last one year's TAC VISTA reading was considered for simulation for heating season.

(6) Inlet and outlet water temperature during cooling season is same for all 20 years cooling season.

(7) Inlet and outlet water temperature during heating season is same for all 20 years heating season.

(8) Average thermocouple readings for 5 days for ground temperatures at 8ft depth during first year's cooling season was considered for 20 years simulation.

5.4.2 Boundary Conditions

Inlet and outlet are constant temperatures wall boundary. Walls are considered to be constant heat flux boundary condition, considering it to be adiabatic wall. Figure 20 and 21 shows inlet and outlet water temperatures during cooling and heating season.

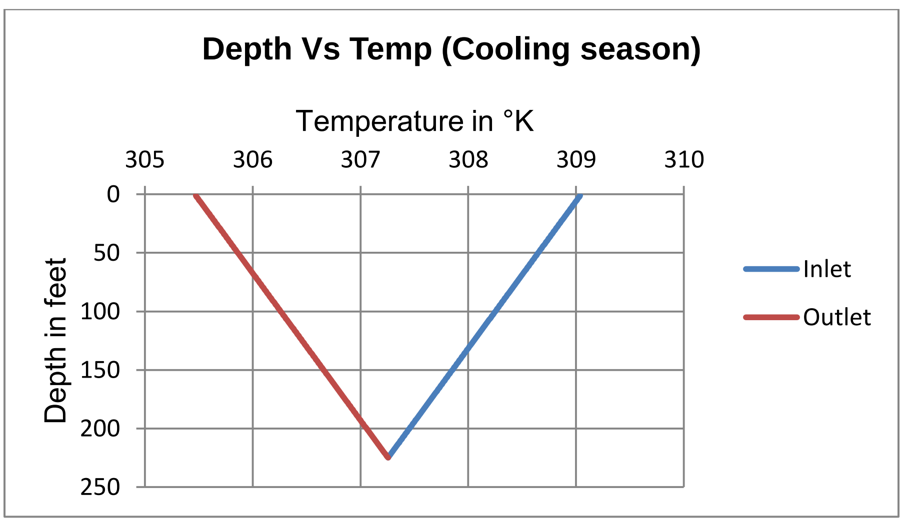



Figure 20: Depth vs. Temperature during Cooling Season

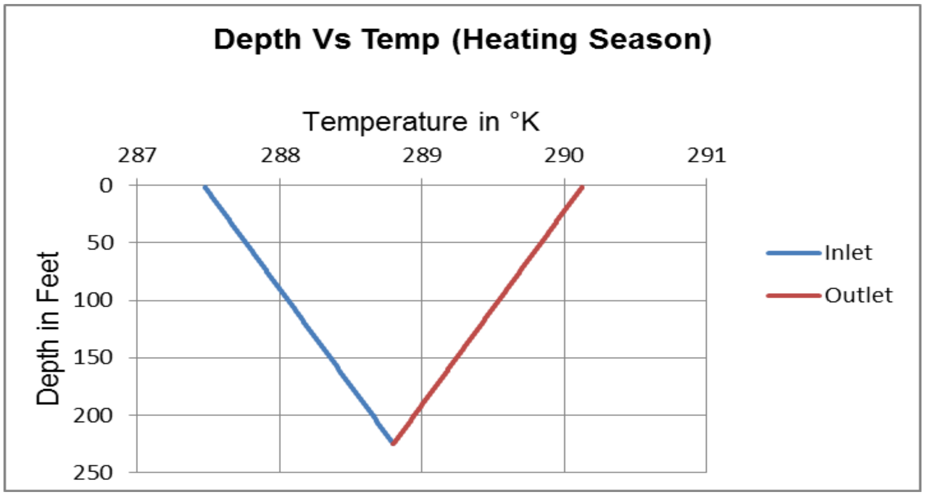



Figure 21: Depth vs. Temperature during Heating Season

Table 7: Boundary Conditions for Effect of Time

| Characteristics | Values |
|---|---|
| Cooling season | |
| Inlet temperature | 308.9740 K |
| Outlet temperature | 305.5370 K |
| Heating season | |
| Inlet temperature | 287.5686 K |
| Outlet temperature | 290.03139 K |
| Side wall heat flux | 0 $W/m^2$ |
| Ground temperature | 299.4 K |
| Time step size | 3600 sec |
| No of steps | |
| 7-5 month | 5040 cooling season, 3720 heating season |
| 6-4 month | 4320 cooling season, 2880 heating season |
| 7-3 month | 5040 cooling season, 2160 heating season |

| | |
|---|---|
| ZØE heating and cooling periods | 6168 cooling season, 2592 heating season |

Simulation period was considered from 1st September 2012 to 31st August 2013. ZØE was constructed in April 2012. Therefore, TAC Vista reading is available from October 2012 to present. For Getting Exact number of heating and cooling days for ZØE, September 2012 data was considered from weather data for Denton, TX [13]. Temperature above cooling set point was considered as cooling season and temperature below cooling set point was considered to be heating season. Figure 22 shows September 2012 number of hours of heating and cooling.

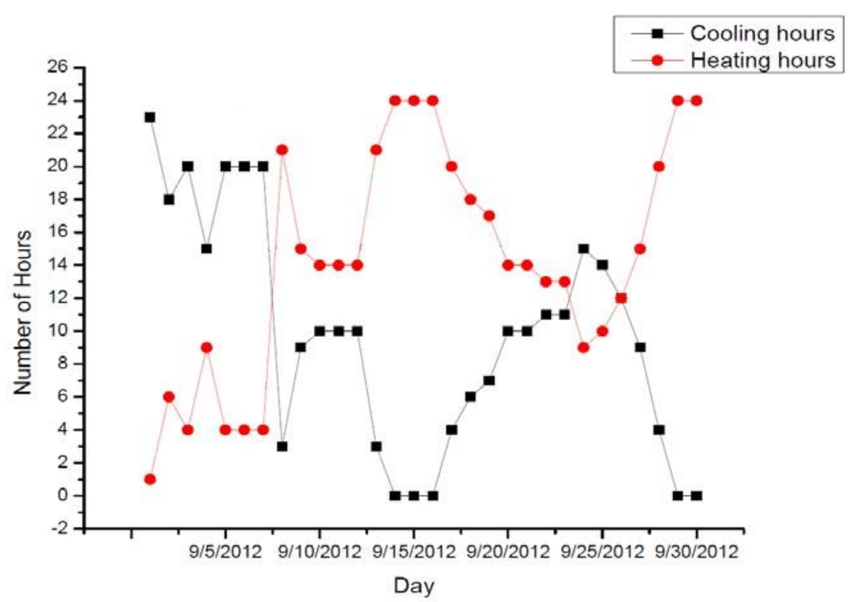



Figure 22: Number of Heating and Cooling Hours in September 2012

### 5.5 Effect of Load and Effect of Doubling ΔT of GLHE

#### 5.5.1 Effect of Load

For effect of l oad following assumption was considered for inlet and outlet temperature.

(1) 8ft depth is considered for simulations.

(2) Maximum load, i.e. maximum temperature difference between inlet and outlet water temperature was considered during cooling season.

(3) Minimum load, i.e. minimum temperature difference between inlet and outlet water temperature was considered during heating season.

(4) Inlet and outlet temperature considered during first year's cooling season is assumed to be same during all 20 years cooling seasons.

(5) Inlet and outlet temperature considered during first year's heating season is assumed to be same during all heating season.

(6) Average thermocouple readings for 5 days for ground temperatures at 8ft depth during first year's cooling season was considered for 20 years simulation.

#### 5.5.2 Boundary Conditions

Figure 23 and 24 shows temperature of water at inlet and outlet at various depths for heating and cooling seasons.

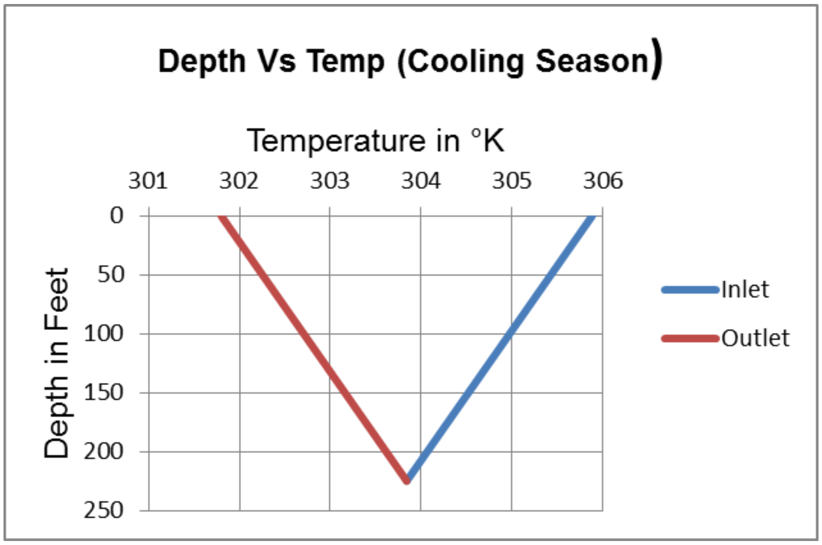



Figure 23: Depth vs. Temperature for Cooling Season

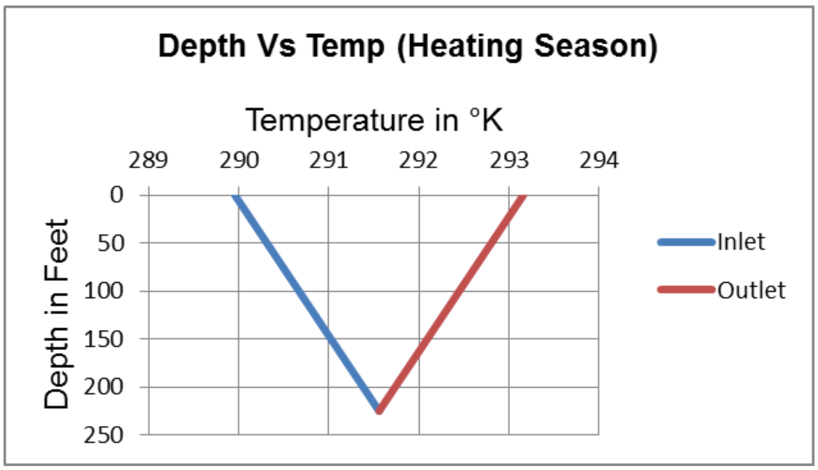



Figure 24: Depth vs. Temperature for Heating Season

ZØE's cooling and heating load depends mainly on weather conditions. To see effect of doubling load on GLHE for soil temperature change. Inlet and outlet temperatures were doubled for heating and cooling season. Figure 25, 26 shows depth versus temperature profile for cooling and heating season.

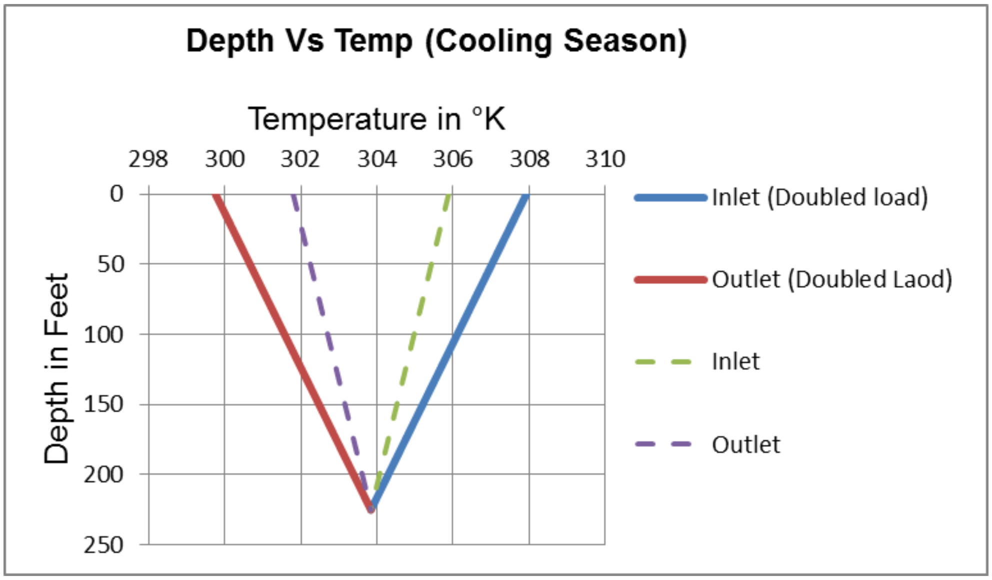



Figure 25: Depth vs. Temperature for Cooling Season

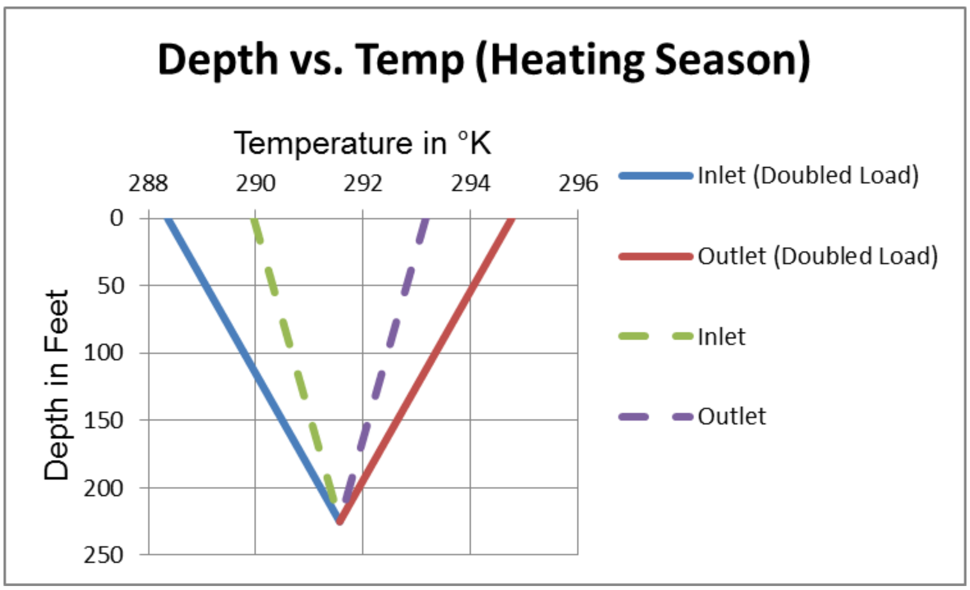



Figure 26: Depth vs. Temperature for Heating Season

Table 8: Boundary Conditions for Effect of Load and Effect of Doubling ΔT of GLHE

| Characteristics | Value |
|---|---|
| Effect of Load | |
| Cooling season | |
| Inlet | 305.8025 K |
| Outlet | 301.8725 K |
| Heating season | |
| Inlet | 290.0169 K |
| Outlet | 293.1031 K |
| Ground temperature | 299. K |
| Time step size | 3600 sec |
| Number of steps | 6168 cooling season, 2592 heating season |
| | |
| Effect of Doubling Load | |
| Cooling season | |
| Inlet | 307.775 K |
| Outlet | 299.905 K |
| Heating season | |
| Inlet | 287.9758 K |
| Outlet | 294.8042 K |
| Ground temperature | 299.4 K |
| Time step size | 3600 sec |
| Number of steps | 6168 cooling season, 2592 heating season |

## 5.6 Effect of Depth

To see effect of depth on soil temperature change, a study was conducted at depth of 4ft, 6ft, 8ft, 110ft and 220ft. Assumptions are as follows.

(1) Soil density for 110ft and 220ft is assumed to be soil density at 13ft.

(2) Thermal conductivity is assumed 1.2 W/m-k throughout all depths.

(3) Time step size is 3600 sec and number of times step is 6168 cooling season and 2592 heating season.

(4) Average thermocouple readings for 5 days for ground temperatures at 4ft, 6ft and 8ft depth during first year's cooling season was considered for 20 years simulation.

(5) Average ground temperature value of 8ft was considered as ground temperature value at 110ft and 220ft.

Table 9: Boundary Conditions for Effect of Depth

| **Characteristics** | **Value** |
|---|---|
| 4ft Depth | |
| Cooling season | |
| Inlet | 309.0065 K |
| Outlet | 305.5045 K |
| Heating season | |
| Inlet | 287.4963 K |
| Outlet | 290.1035 K |
| Soil density | 1591 $kg/m^3$ |
| Ground temperature | 300.16 K |
| 6ft Depth | |
| Cooling season | |
| Inlet | 308.9903 K |
| Outlet | 305.5207 K |
| Heating season | |
| Inlet | 287.5084 K |
| Outlet | 290.09149 K |
| Soil density | 1570 $kg/m^3$ |
| Ground temperature | 299.74 K |

| | | | |
|---|---|---|---|
| 8ft Depth | | | |
| | Cooling season | | |
| | | Inlet | 308.983 K |
| | | Outlet | 305.528 K |
| | Heating season | | |
| | | Inlet | 287.514 K |
| | | Outlet | 290.086 K |
| | Soil density | | 1579.42 kg/m$^3$ |
| | Ground temperature | | 299.4 K |
| 110ft Depth | | | |
| | Cooling season | | |
| | | Inlet | 308.1712 K |
| | | Outlet | 306.3399 K |
| | Heating season | | |
| | | Inlet | 288.1182 K |
| | | Outlet | 289.4817 K |
| | Soil density | | 1839 kg/m$^3$ |
| | Ground temperature | | 299.4 K |
| 220ft Depth | | | |
| | Cooling season | | |
| | | Inlet | 307.2954 K |
| | | Outlet | 307.2157 K |
| | Heating season | | |
| | | Inlet | 288.7702 K |
| | | Outlet | 288.8297 K |
| | Soil density | | 1839 kg/m$^3$ |
| | Ground temperature | | 299.4 K |

### 5.7 Soil Temperature Change if Same ZØE Building is at Miami, Florida

In this case, same parameters like size, load and same number of occupants were considered for simulating effects of soil temperature change for ZØE building in Miami, Florida. Inlet and outlet water temperature for GLHE is considered same as of ZØE in Denton, TX, as Miami's highest and lowest temperature is almost equal to Denton, TX. Equivalent number of cooling and heating day data were collected from weather temperatures for every hour for one year [13]. For this case set-point for cooling season is considered as 70 °F and above. Transition period is when no heating or cooling is required and GSHP will be OFF, set- point for transition period is between 65 °F to 70 °F. Heating season set-point is 65°F and below.

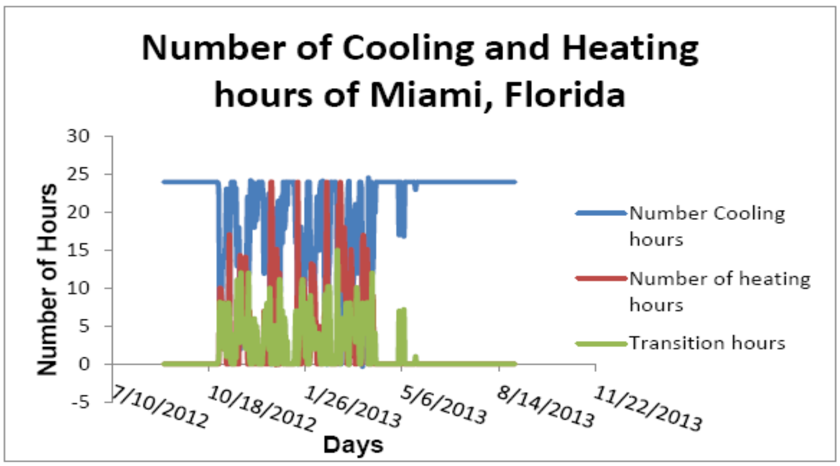



Figure 27: Number of Heating and Cooling Hours per Day from September 2012 to August 2013 for Miami, Florida

Table 10: Boundary Conditions for ZØE in Miami, Florida Case

| Characteristics | | Values |
|---|---|---|
| Cooling Season | Inlet | 308.9740 K |
| | Outlet | 305.5370 K |
| Heating Season | Inlet | 287.5686 K |
| | Outlet | 290.03139 K |
| Soil Density | | 1630 kg/m$^3$ |
| Time step size | | 3600 sec |
| Number of steps | | 3449 cooling season, 5311 heating season |

CHAPTER 6

RESULTS AND DISCUSSION

ZØE's heating or cooling depends on weather conditions. Simulation data for first year is considered from October 2012 to September 2013. Figure 28 shows inlet temperature to GLHE from October 2012 to September 2013. Figure 29 shows WWHP load of ZØE from February 2013 to September 2013

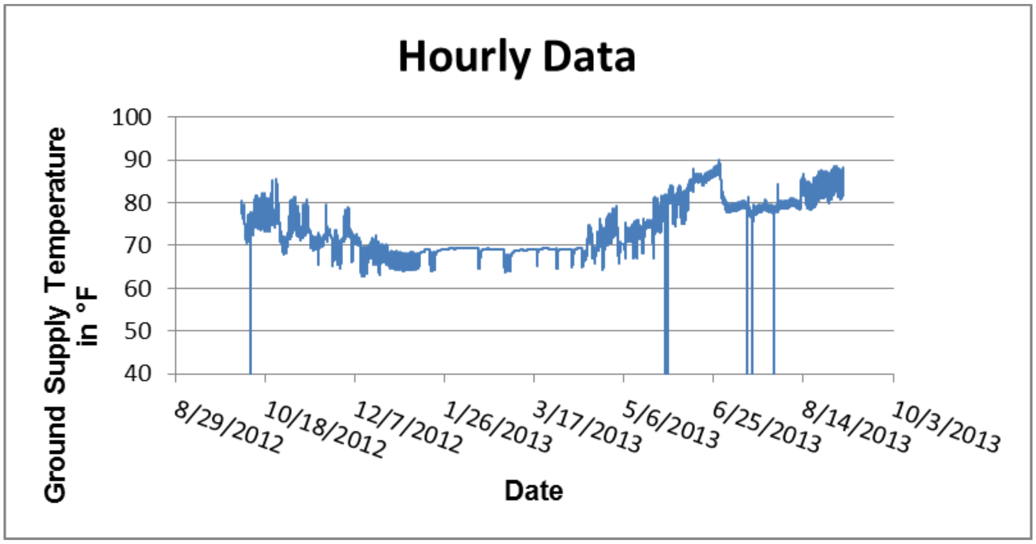



Figure 28: Ground Water Inlet Temperature from October 2012 to September 2013

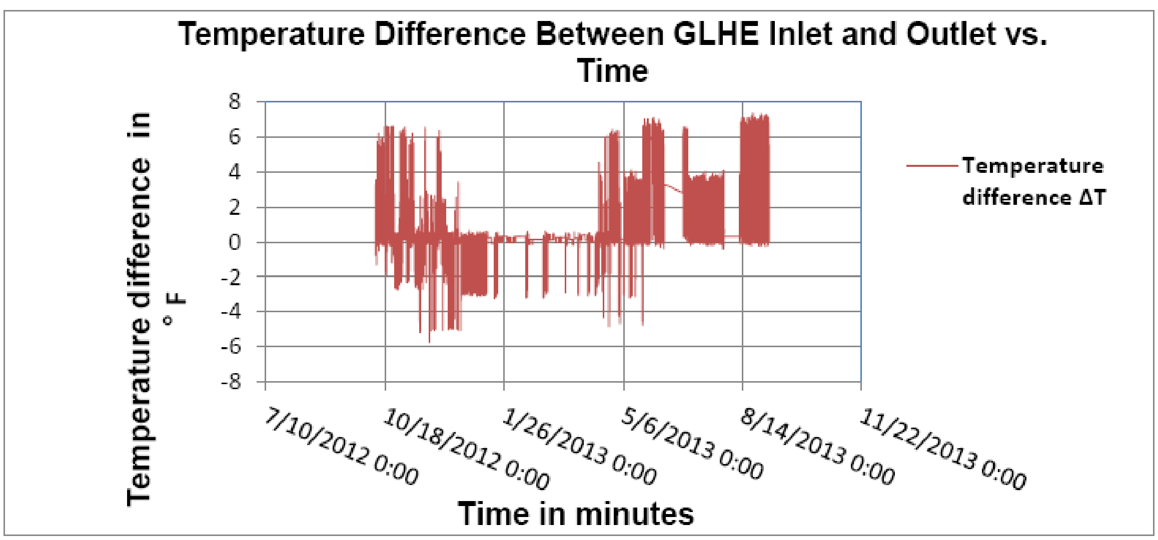



Figure 29: Temperature Difference between GLHE's Input and Output vs. Time

A study was conducted on effect of time, load and depth to get soil temperature change caused by GLHE. Soil temperature distribution is showed along red line for all the following results (Figure 30).

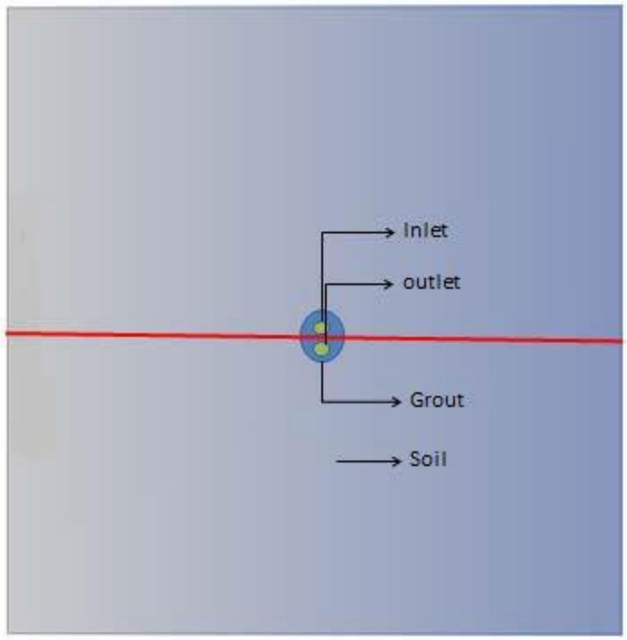



Figure 30: Temperature Distribution of Soil is carried along Red Line for Result Simulation

## 6.1 Effect of Time

### 6.1.1 Effect of Time for 7 Months Cooling Season – 5 Month Heating Season

Numbers of time steps are 5040 cooling season and 3720 heating season. Simulation was carried out for 20 years. Input and output water temperature was changed for every season and every year for transient simulation. Following is temperature distribution of soil for 1$^{st}$ year, 5$^{th}$ year, 10$^{th}$ year 15$^{th}$ year and 20$^{th}$ year.

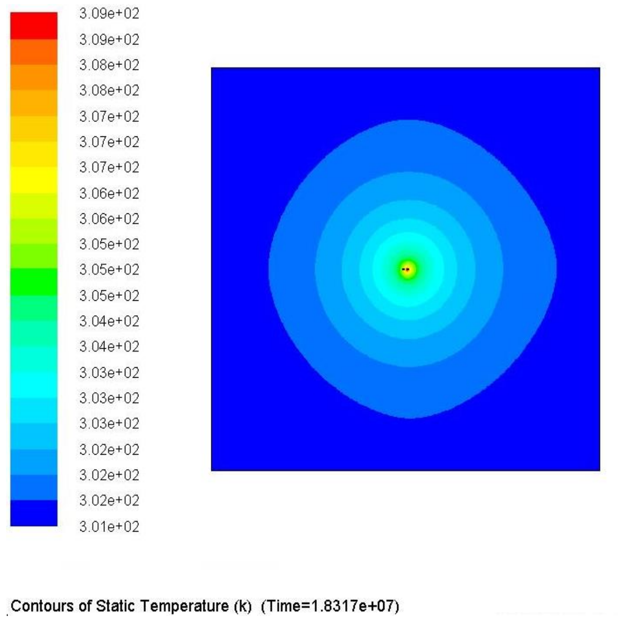



Figure 31:1st year Cooling seasons temp contour

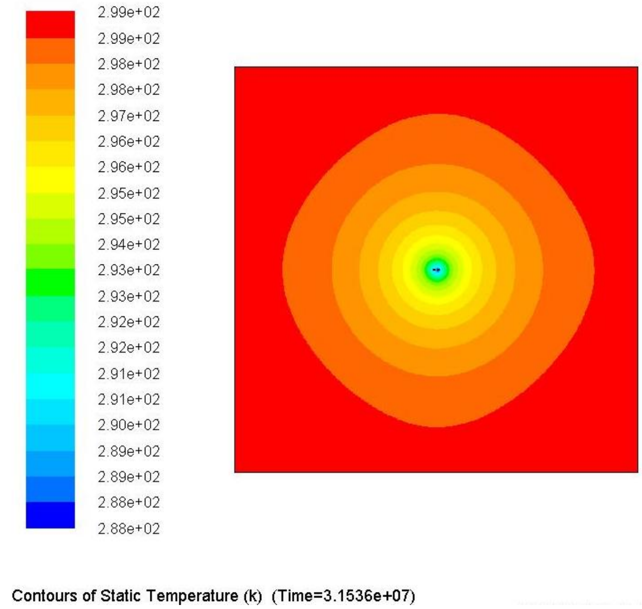



Figure 32: 1st year Heating seasons temp contour

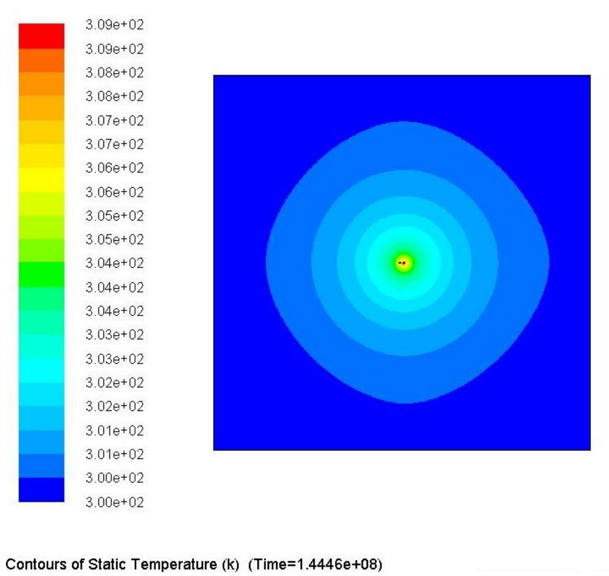



Figure 33: 5th year Cooling seasons temp contour

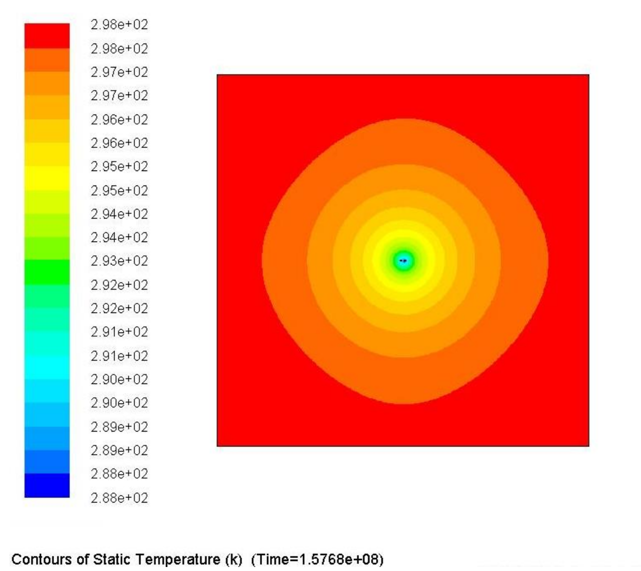



Figure 34: 5th year Heating seasons temp contour

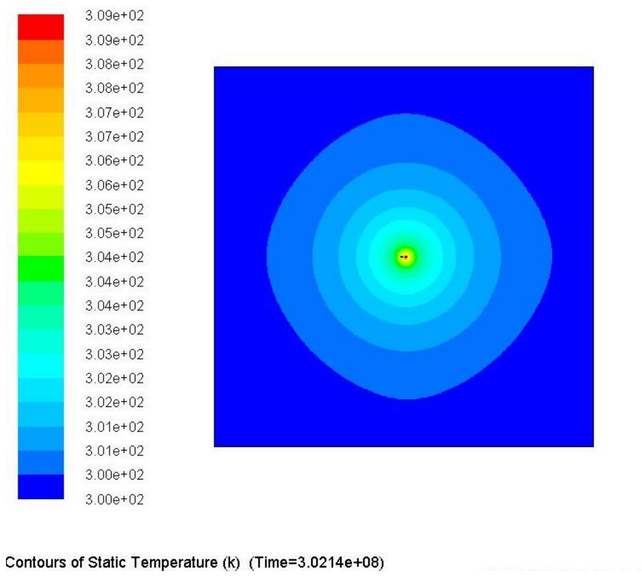



Figure 35: 10th year Cooling seasons temp contour

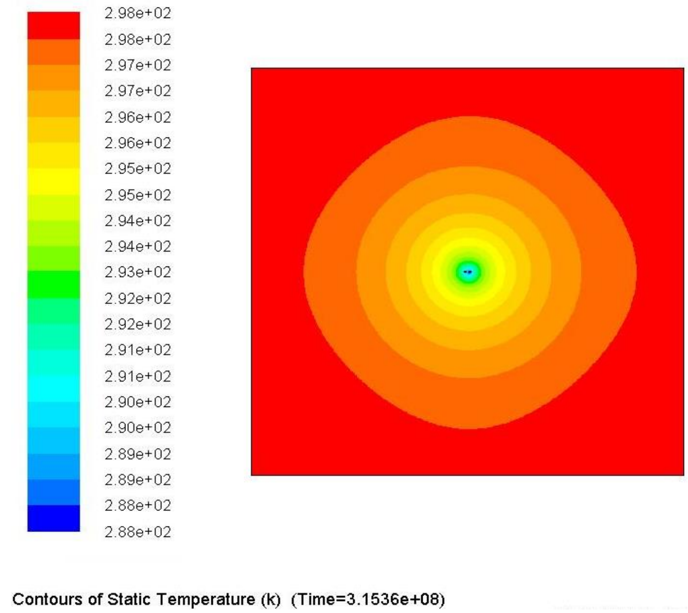



Figure 36: 10th year Heating seasons temp contour

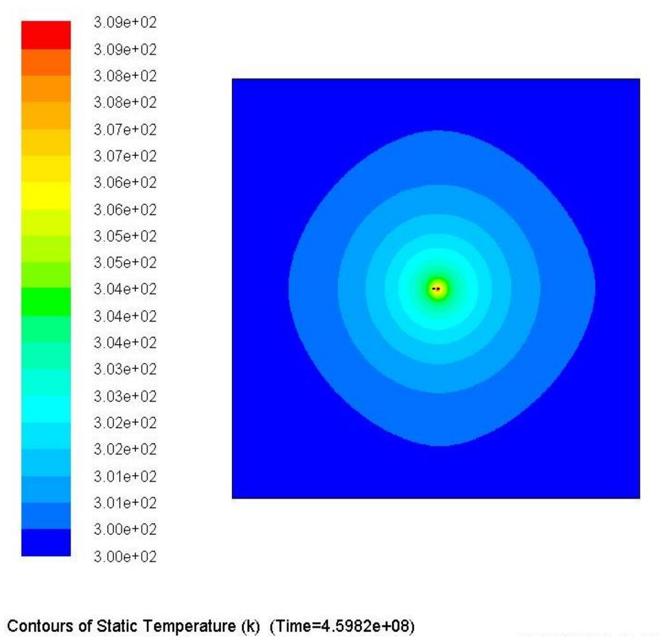



Figure 37: 15th year Cooling seasons temp contour

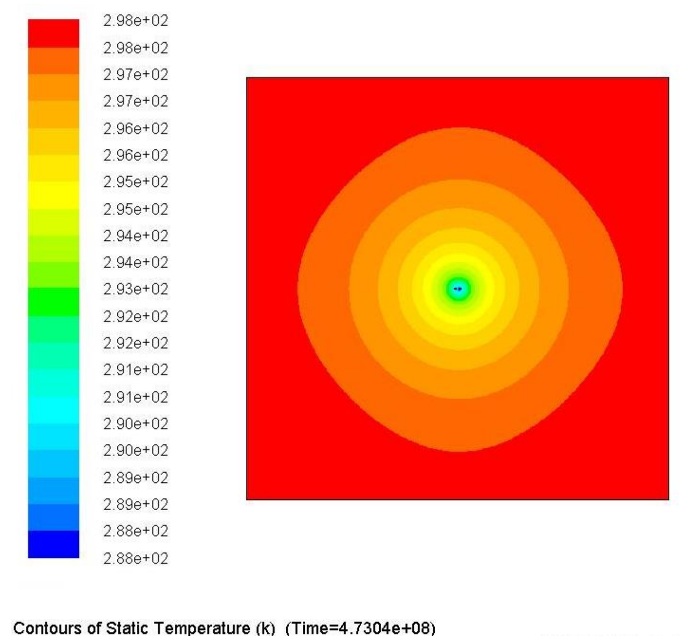



Figure 38: 15th year Heating Seasons temp contour

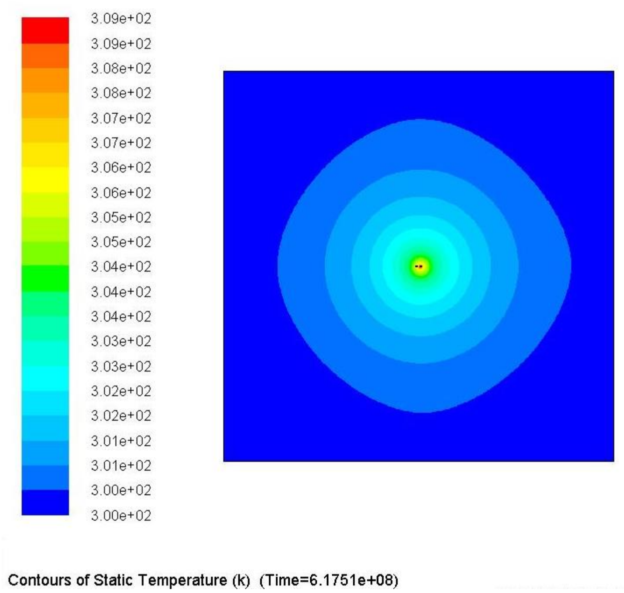



Figure 38: 20th year cooling seasons temp contour

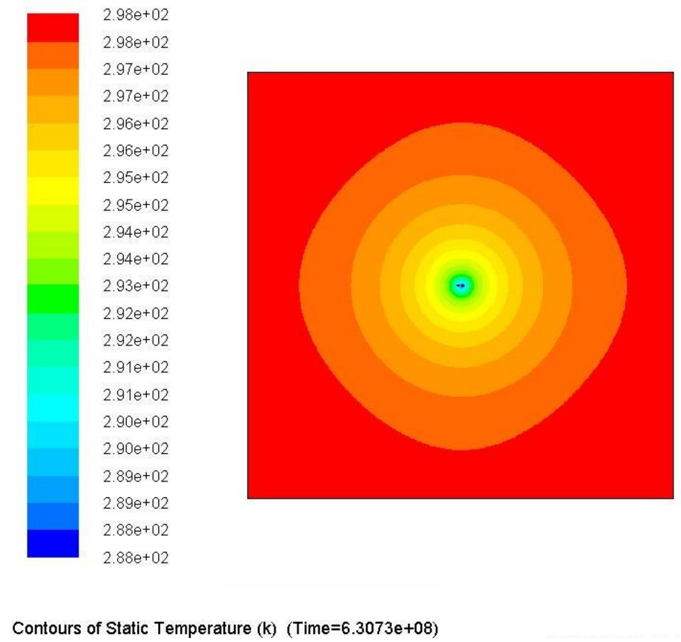



Figure 39: 20th year heating seasons temp contour

For simulation, season starts with cooling season and end with heating season. Figure 41 shows soil temperature distribution along red line after 1st years heating season to 20th years heating season.

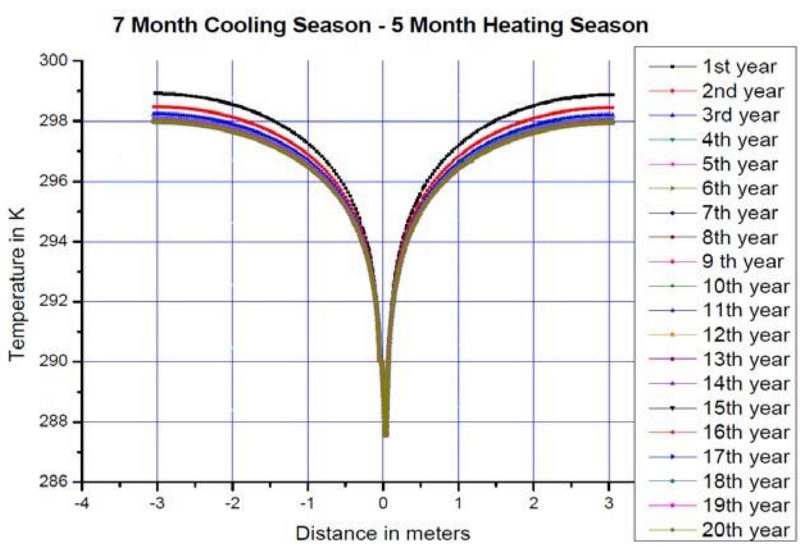



Figure 41: Soil Temperature Distribution of Red Line from 1st Year to 20th Year

Temperature difference between 1st year and 20th year soil temperature is -1.420 °C. Temperature of soil is reducing in this case as heating season period is 5 month.

6.1.2 Effect of Time for 6 Months Cooling Season and 4 Months Heating Season

In this case GSHP is assumed to be off for 2 months, so there will be no flow of water for two months. Cooling season is assumed to be 6 month and heating season is assumed to be 4 month. Table 7 explains boundary conditions details. Following figures show soil temperature distribution contours of 1st year, 5th year, 10th year, 15th year and 20th year.

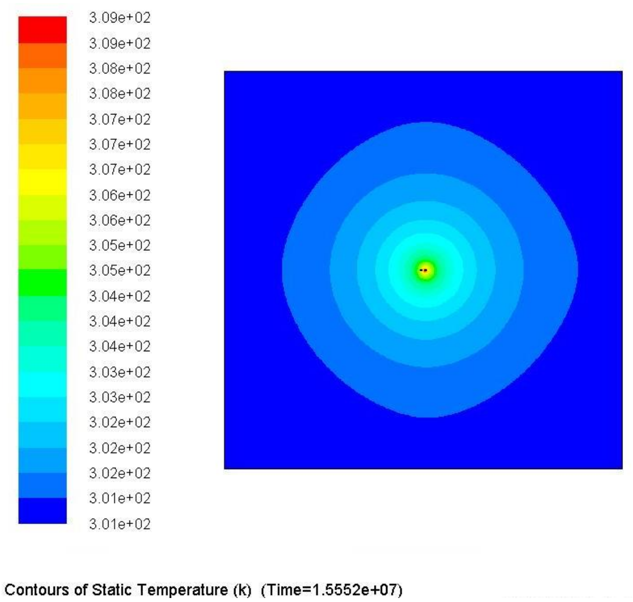



Figure 42: 1st year cooling seasons temp contour

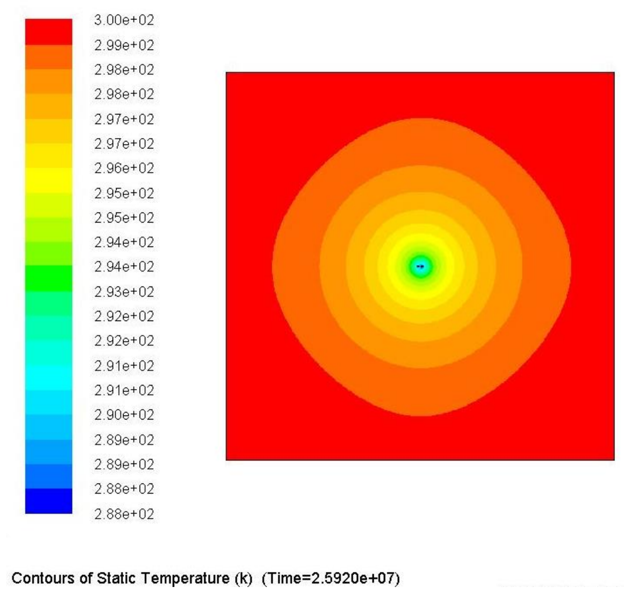



Figure 43: 1st year heating season temp contour

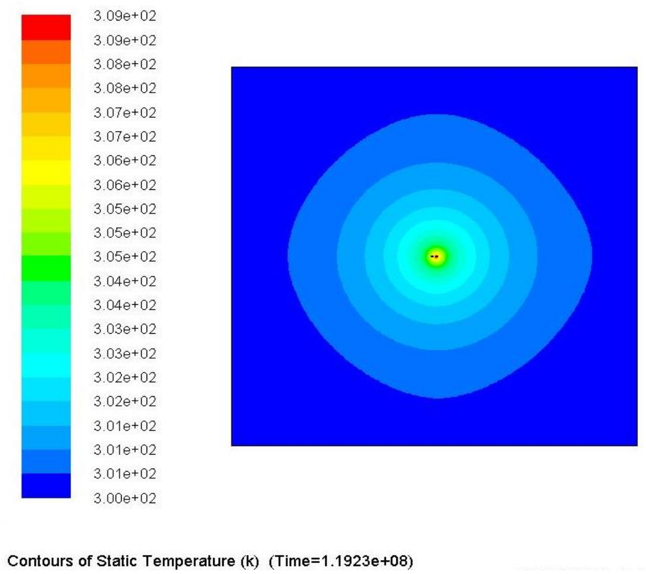



Figure 44: 5th year cooling seasons temp contours

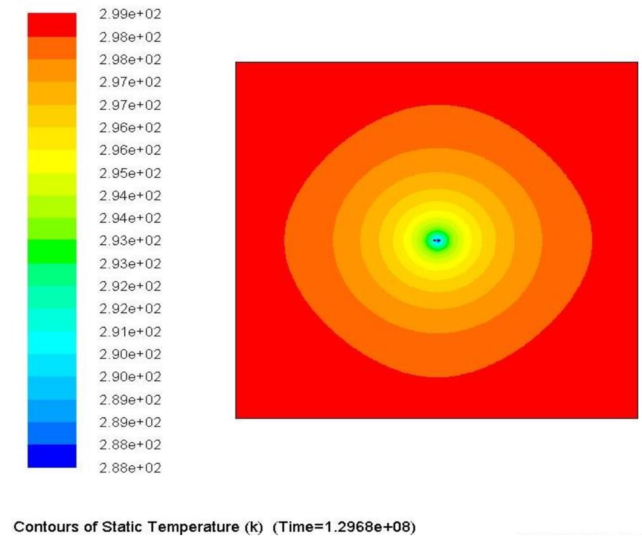



Figure 45: 5th year heating season temp contour

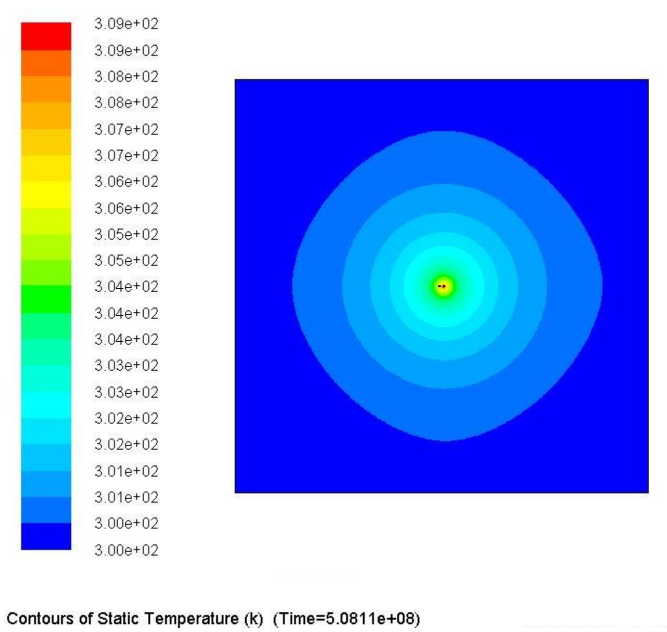



Figure 46: 20th year cooling seasons temp contour

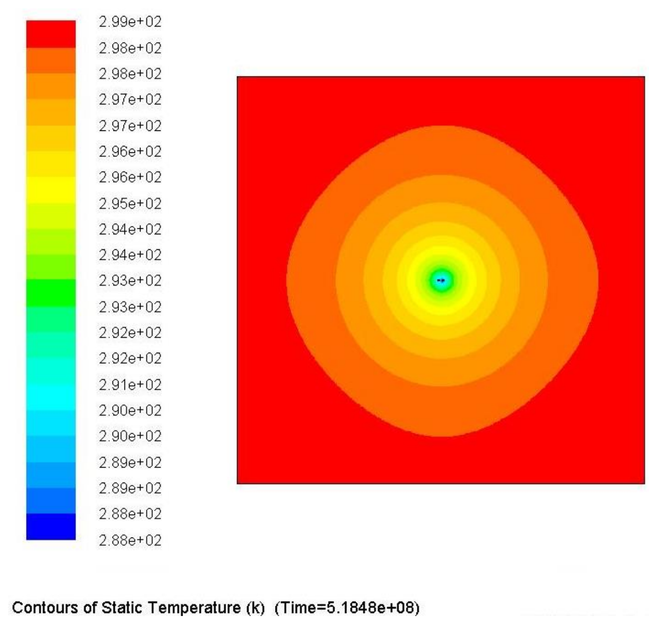



Figure 47: 20th year heating seasons temp contour

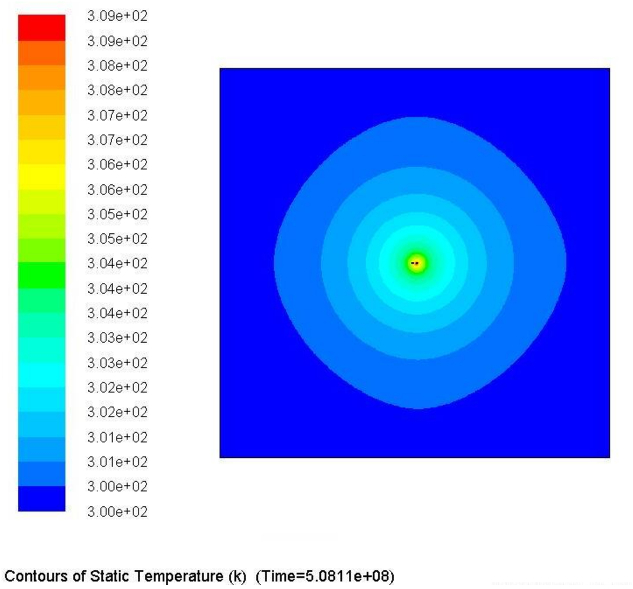



Figure 48: 20th Year Cooling Seasons Temp Contour

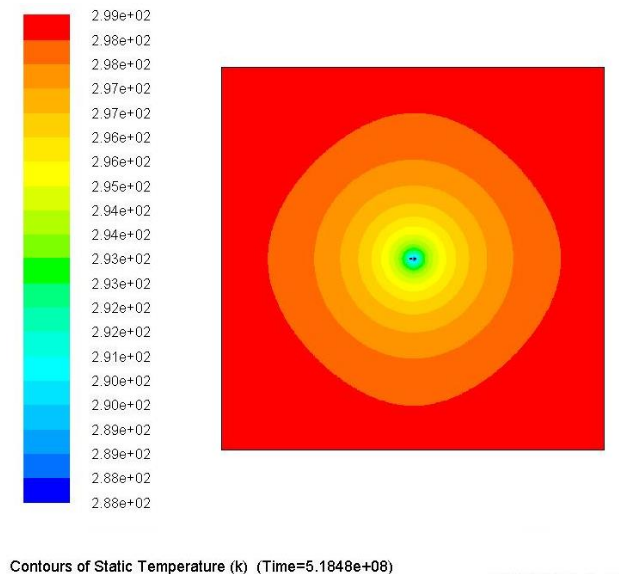



Figure 49: 20th Year Heating Seasons Temp Contour

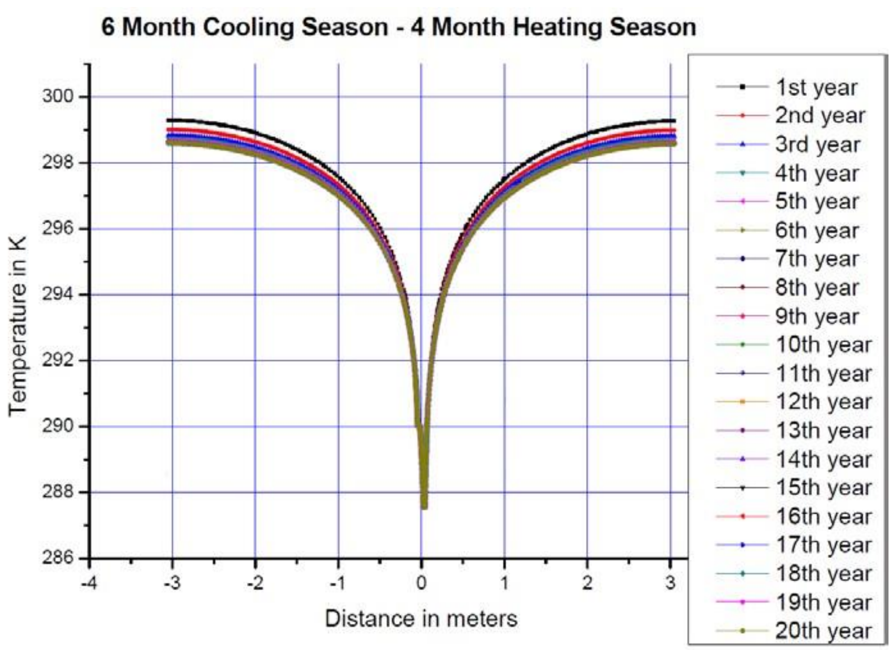



Figure 50: Temperature Distribution along Red Line (Figure 30) from 1st Year to 20th Year

After simulating for above case, temperature difference between initial year and 20th year is -0.798 °C. So, after 20th year soil will cool down to -0.798 °C from initial year.

6.1.3 Effect of Time for 7 Month Cooling Season and 3 Months Heating Season

In this case GSHP is assumed to be off for 2 month. Table 7 gives Boundary condition details. Cooling for 7 months (5040 steps) and heating for 3 months (2160 steps) is assumed for 20 years simulation. Following figure shows soil temperature distribution of from 1st year, 5th year, 10th year and 20th year. This is one of case that can happen in Denton, TX.

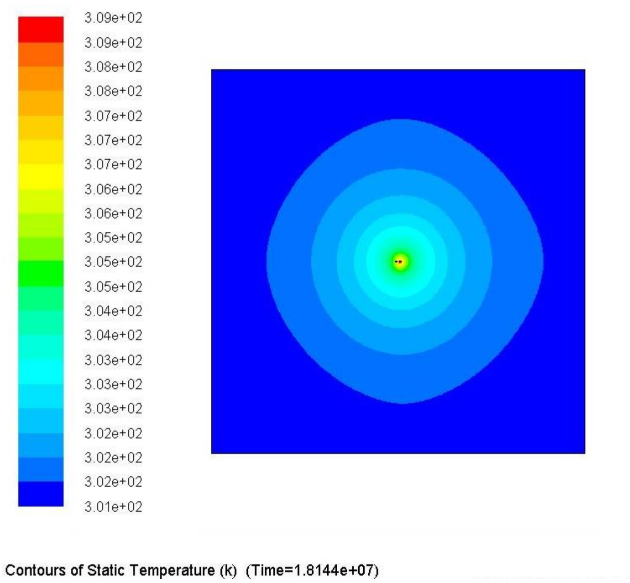



Figure 51: 1st Year Cooling Seasons Temp Contour

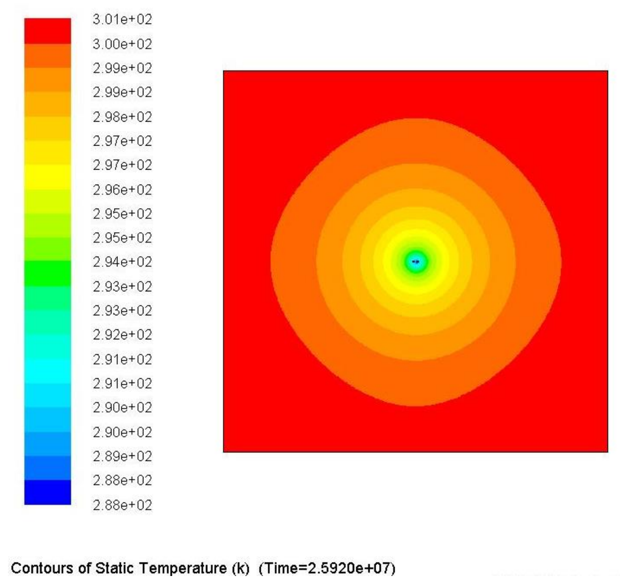



Figure 52: 1st Year Heating Seasons Temp Contour

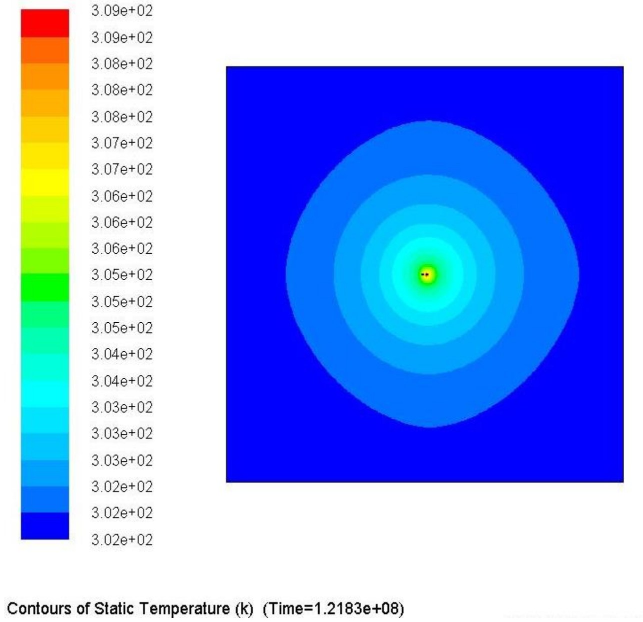



Figure 52: 5th Year Cooling Seasons Temp Contour

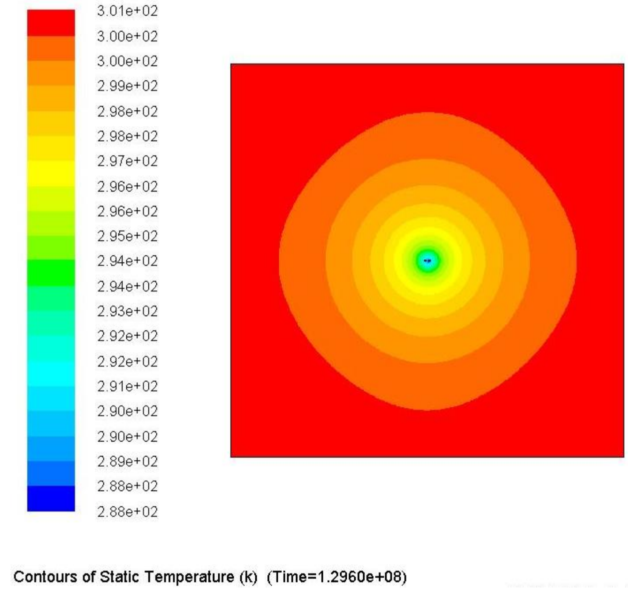



Figure 53: 5th Year Heating Season Temp Contour

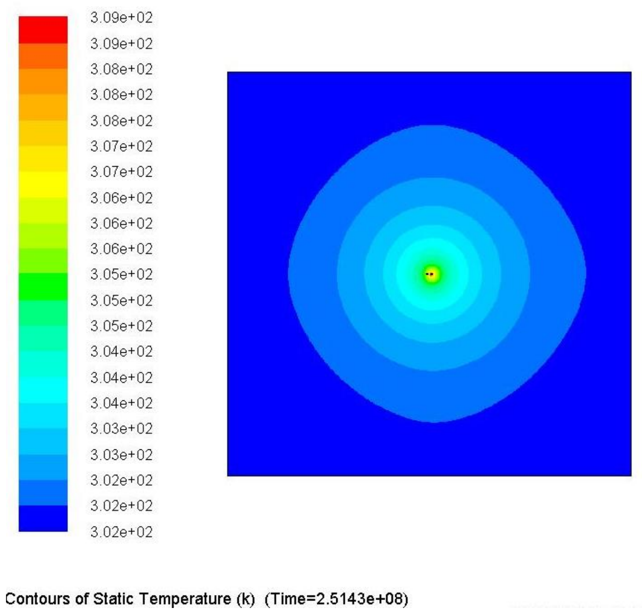



Figure 54: 10th year cooling seasons temp contour

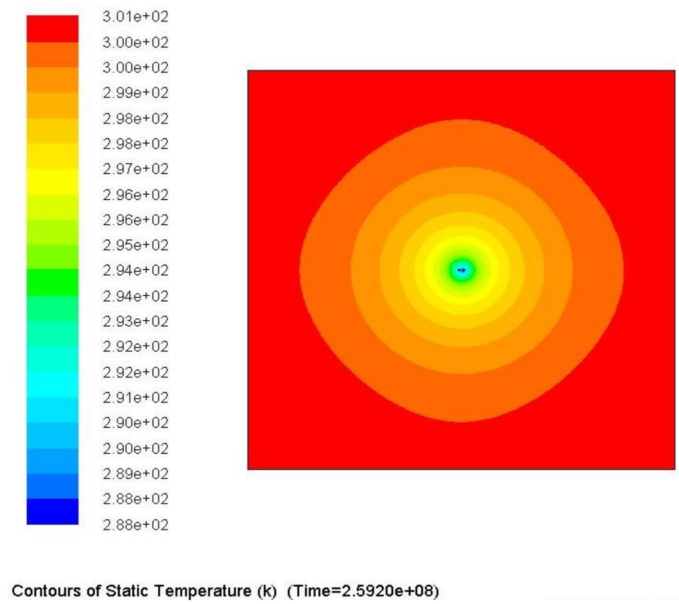



Figure 55: 10th year heating seasons temp contour

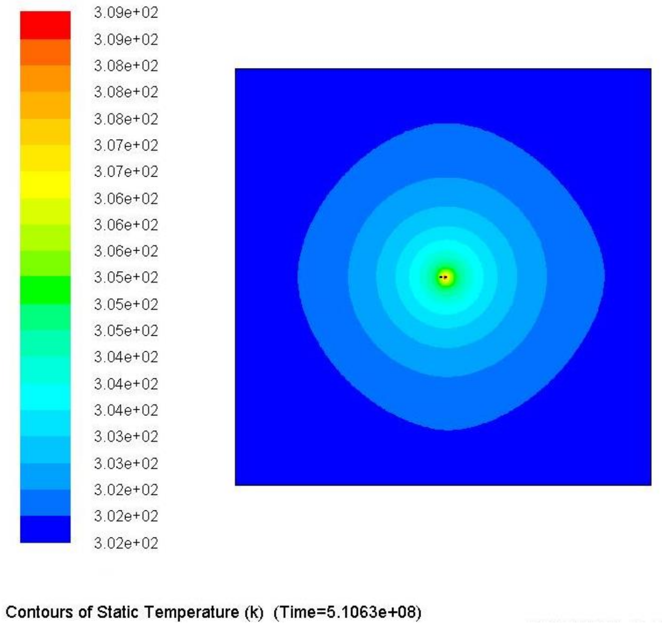



Figure 57: 20th year cooling season temp contour

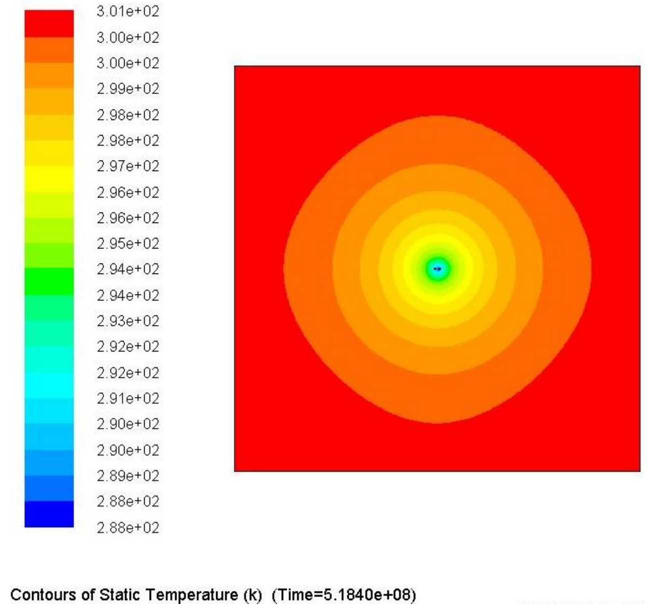



Figure 58: 20th year heating season temp contour

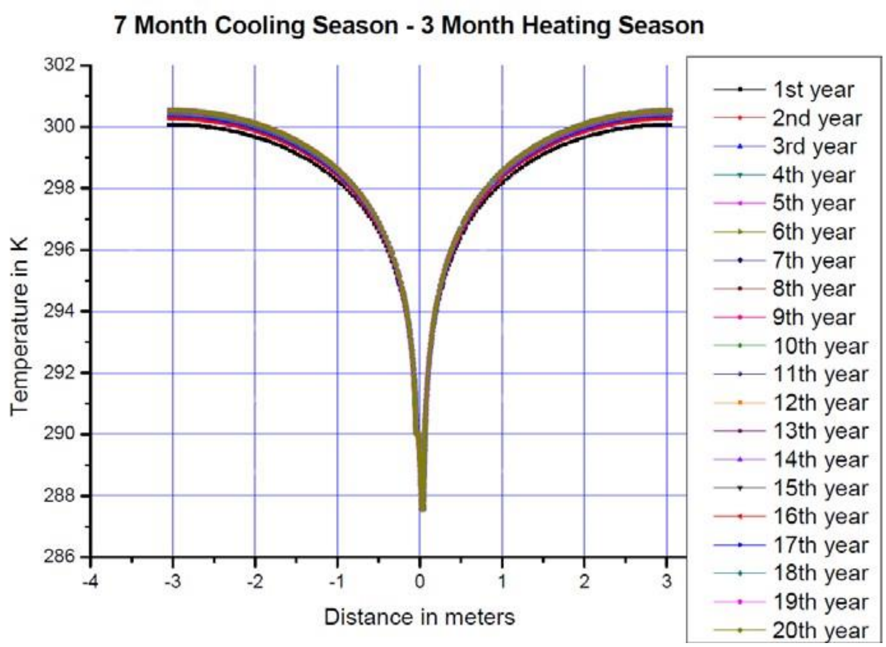



Figure 59: Soil Temperature Distribution along Red Line Figure 30 from 1st Year to 20th Year

After simulating for 7 month cooling and 3 month heating season case, there is increase in soil temperature by 1.137 °C after 20th year. As year passes soil temperature keep on increasing.

6.1.4 Effect of Time for ZØE's Heating and Cooling Season

Temperature difference between water inlet and outlet of GLHE's reading from TAC VISTA helped to find number of heating and cooling season for ZØE. Boundary conditions are given in table 7. Number of time step for cooling/heating are 6168/2592. This is actual ZØE case. Below figures shows temperature distribution for 1$^{st}$, 5$^{th}$, 10$^{th}$ and 20$^{th}$ year.

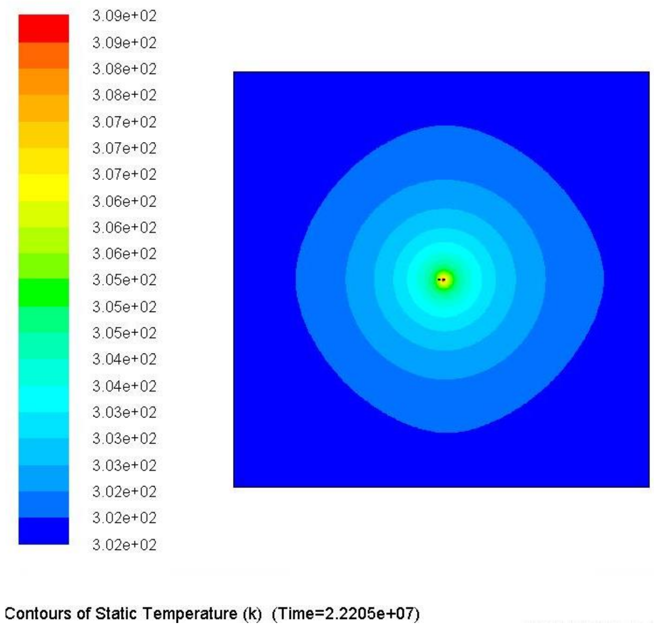



Figure 60: 1$^{st}$ Year Cooling Seasons Temp Contour

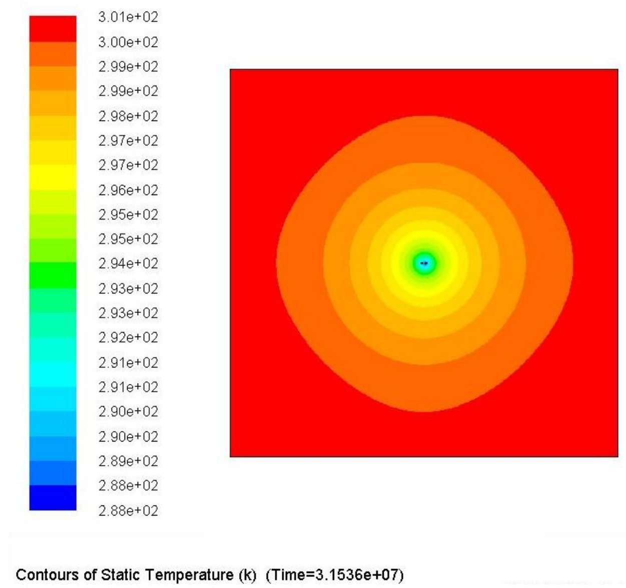



Figure 61: 1$^{st}$ Year Heating Season Temp Contour

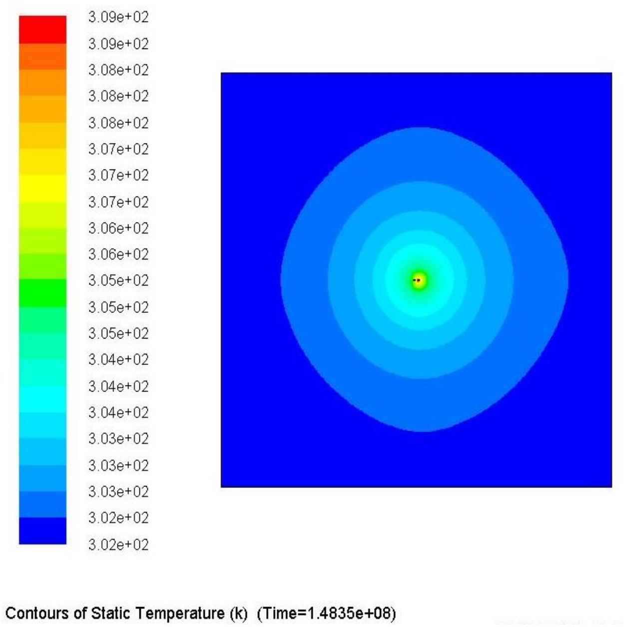



Figure 62: 5th Year Cooling Seasons Temp Contour

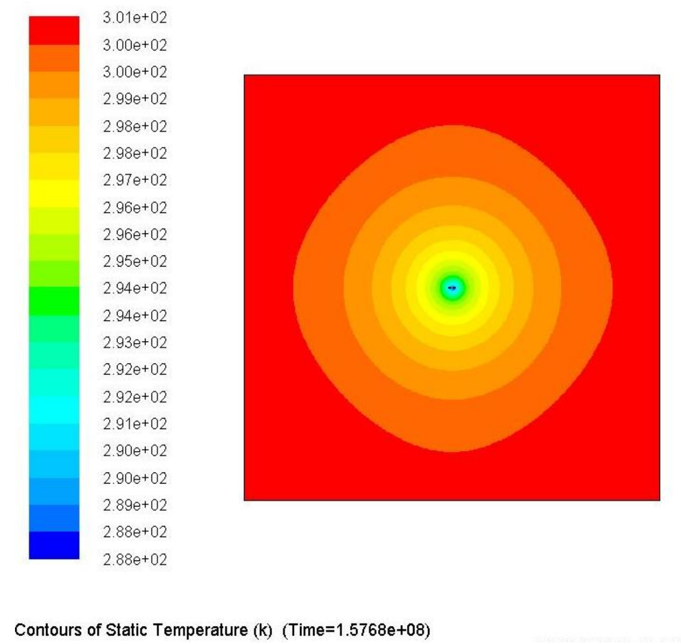



Figure 63: 5th Year Heating Season Temp Contour

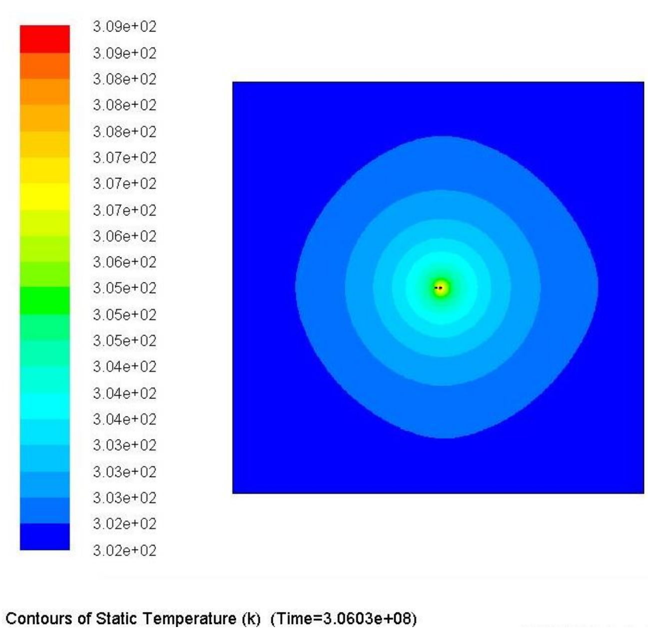



Figure 64: 10th Year Cooling Seasons Temp Contour

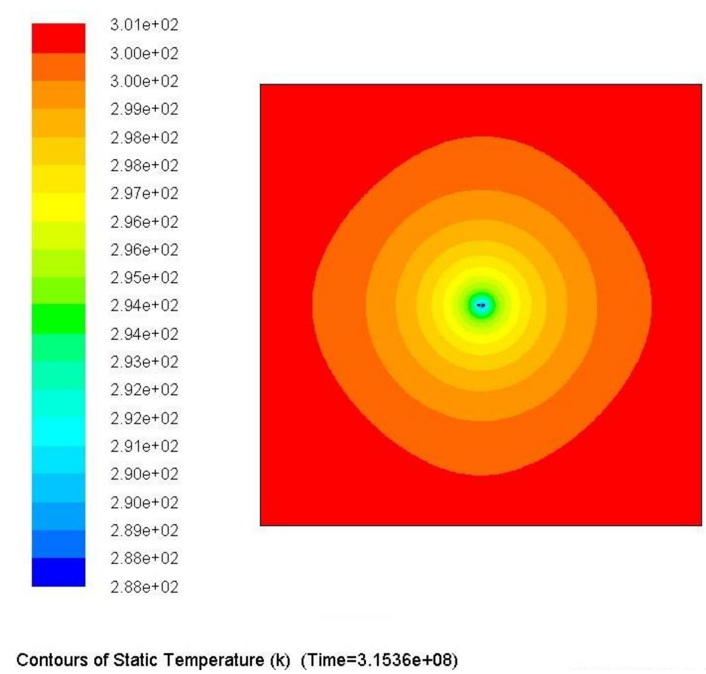



Figure 65: 10th Year Heating Season Temp Contour

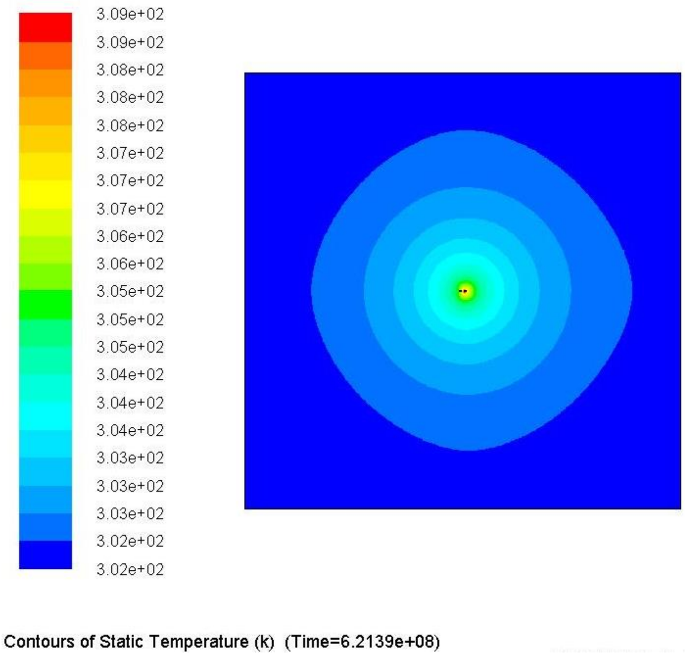



Figure 66: 20th Year Cooling Season Temp Contour

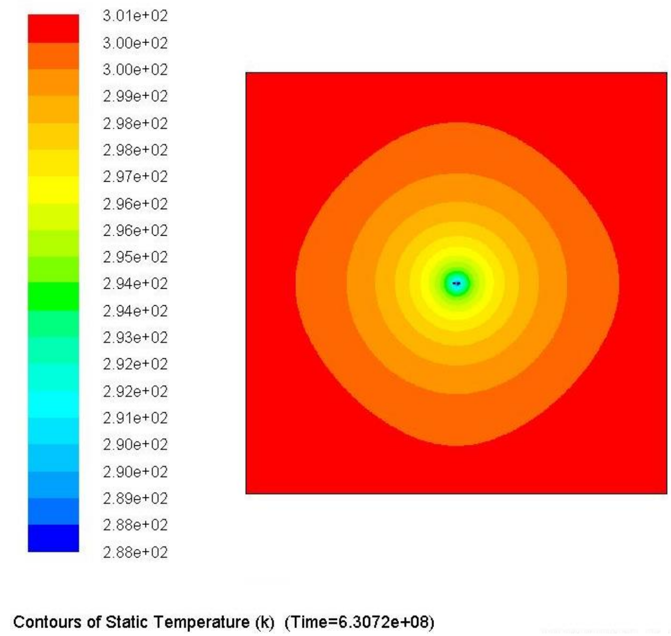



Figure 67: 20th Year Heating Season Temp Contour

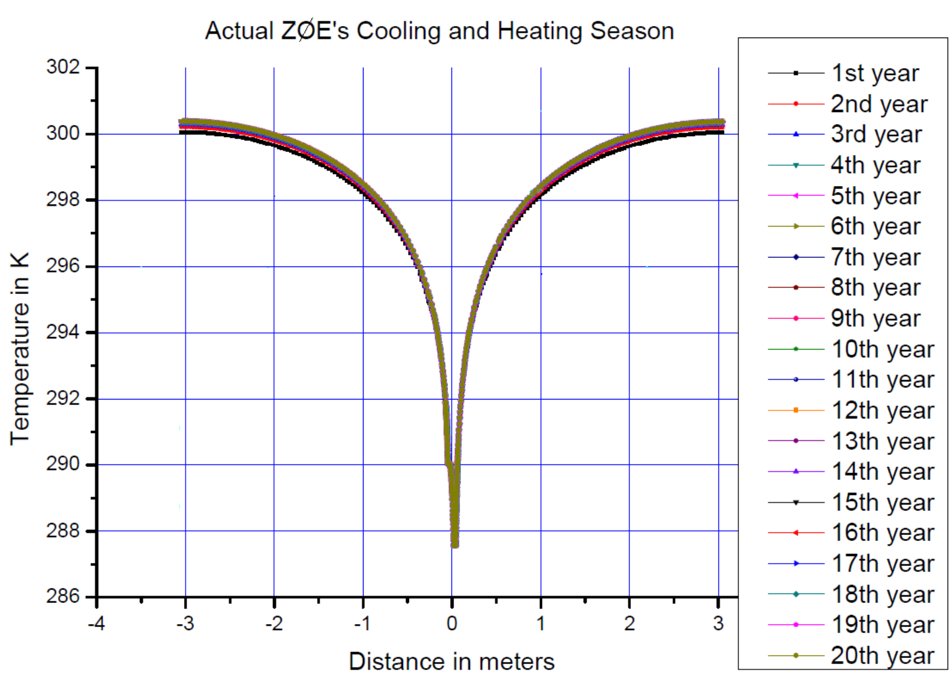



Figure 68: Soil Temperature Distribution for Red Line (Figure 30) for ZØE's Cooling and Heating Season

From simulation, soil temperature will increase by 0.988 °C after 20th year. At start of cooling season, initial year temperature difference between center of two pipes and soil at the end of walls of one well is 7.855°C. After end of 20th year and start of 21st year's cooling season, temperature difference between center of two pipes and soil at end of walls of well is 6.875°C. Heat flow rate between center of two pipes and soil reduces after 20th year, which affects COP of GSHP. Heat transfer rate is shown below,

| Year | Heat Transfer Rate in Cooling season (MJ/season) | Heat Transfer Rate in Heating season (MJ/season) | Total Heat Transfer Rate (MJ/season) |
|---|---|---|---|
| 1st year | 205.621 | -192.199 | 13.421 |
| 2nd year | 186.351 | -198.847 | 12.549 |

After 1st year 13.421 MJ/year will be added to 2nd year's summer season. Thus, heat transfer rate goes on decreasing as year passes. Table 11 summaries soil temperature difference for all cases for effect of time.

Table 11: Soil Temperature Change for Effect of Time

| Case | Soil temperature difference from initial year to 20th year (°C) |
|---|---|
| 7 months cooling – 5 months heating season | -1.420 |
| 6 months cooling -4 months heating season | -0.798 |
| 7 months cooling- 3 months heating season | 1.137 |
| 257 days cooling-108 days heating season | 0.988 |

6.2 Effect of Load on Soil Temperature Change

Assumptions and boundary conditions for this case are specified in 5.4 and table 8. Maximum temperature difference between inlet and outlet temperature of GLHE is considered for cooling season, which is maximum load during cooling. Minimum temperature difference between inlet and outlet of GLHE is considered for heating season, which is maximum load during heating. Following figures shows soil temperature distribution along red line (figure 30) for 1st, 5th, 10th and 20th year.

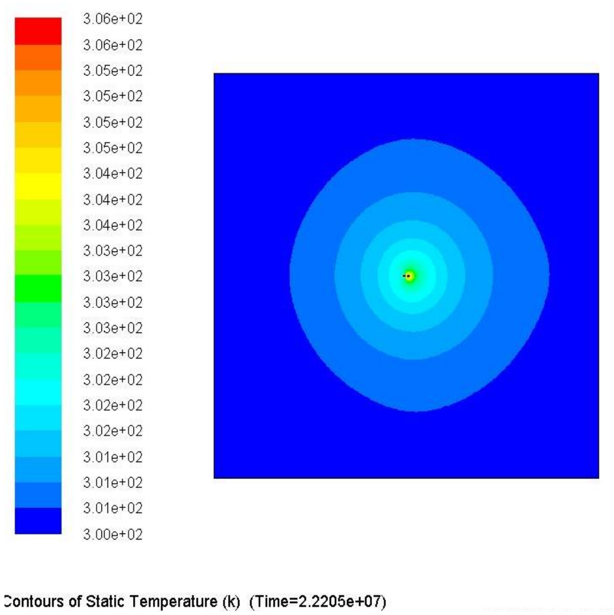



Figure 69: 1st Year Cooling Seasons Temp Contour

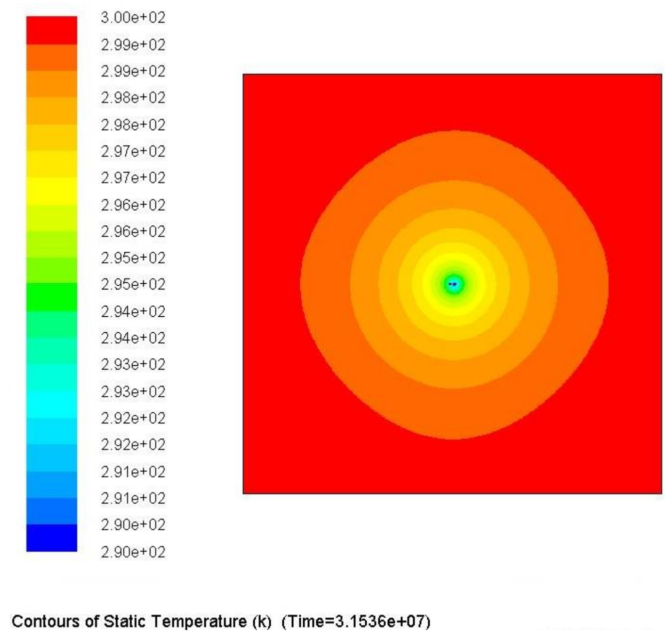



Figure 70: 1st Year Heating Seasons Temp Contour

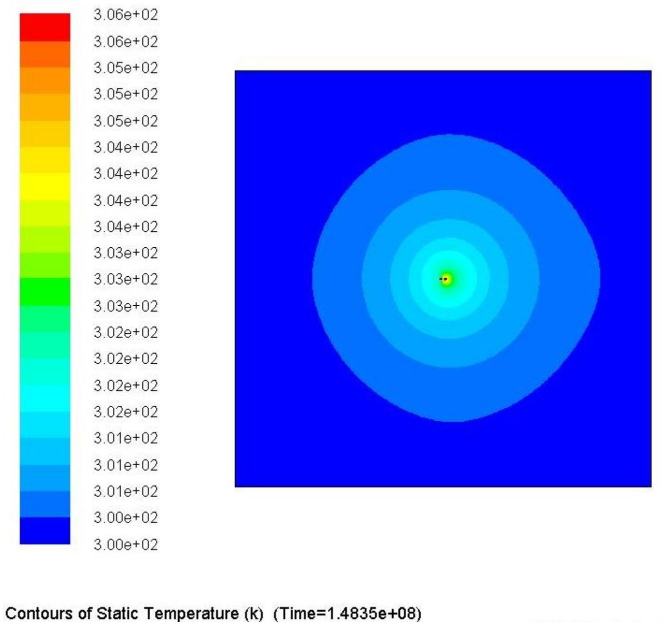



Figure 71: 5th Year Cooling Season Temp Contour

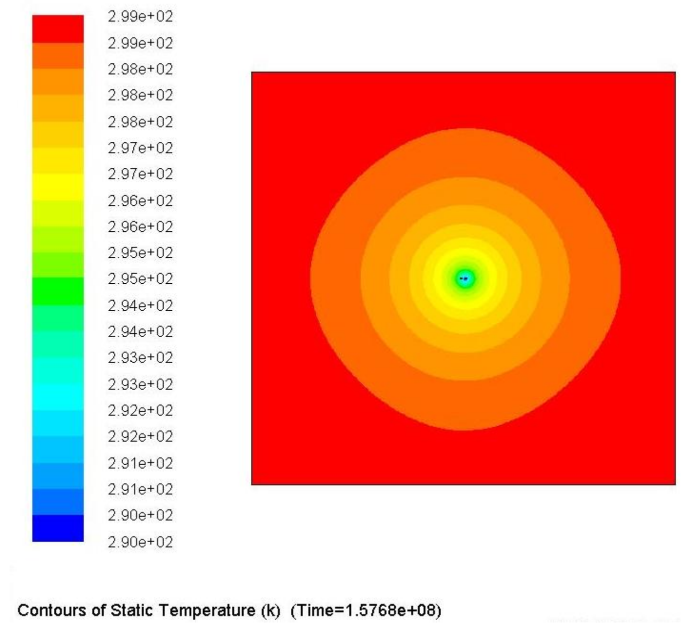



Figure 72: 5th Year Heating Seasons Temp Contour

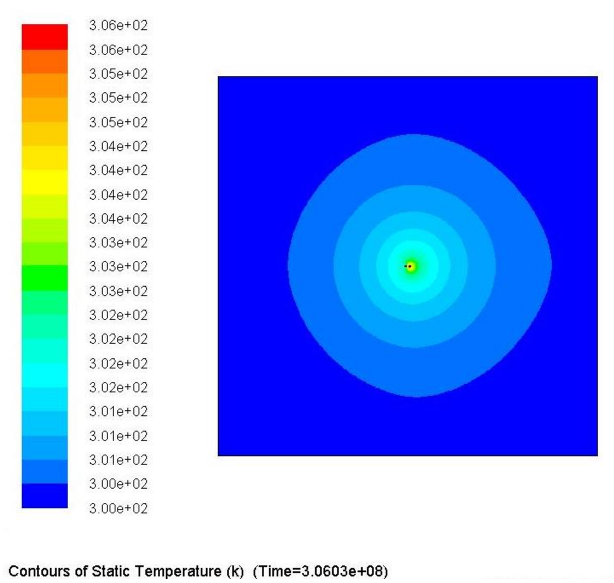



Figure 73: 10th Year Cooling Seasons Temp Contour

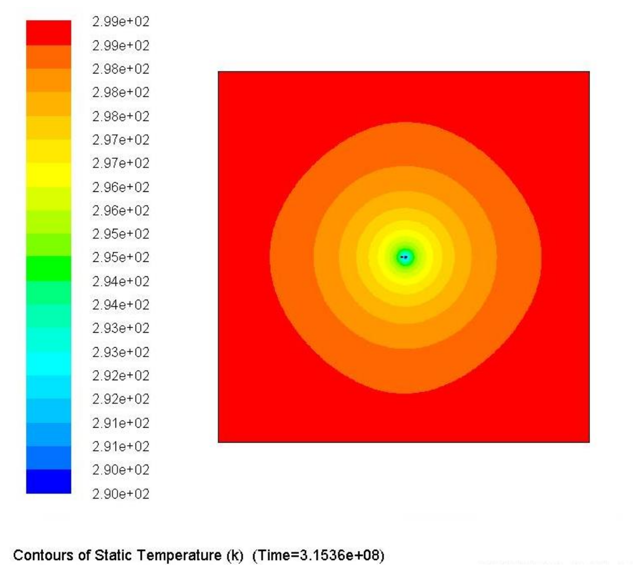



Figure 74: 10th Year Heating Seasons Temp Contour

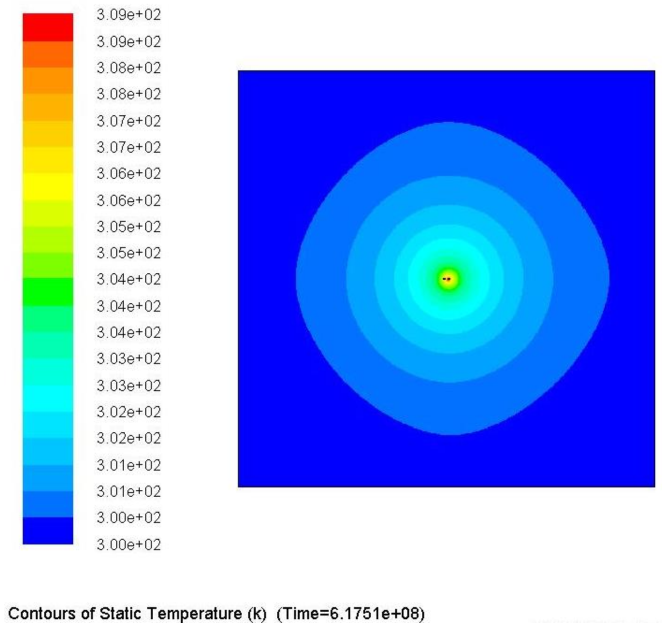



Figure 75: 20th Year Cooling Seasons Temp Contour

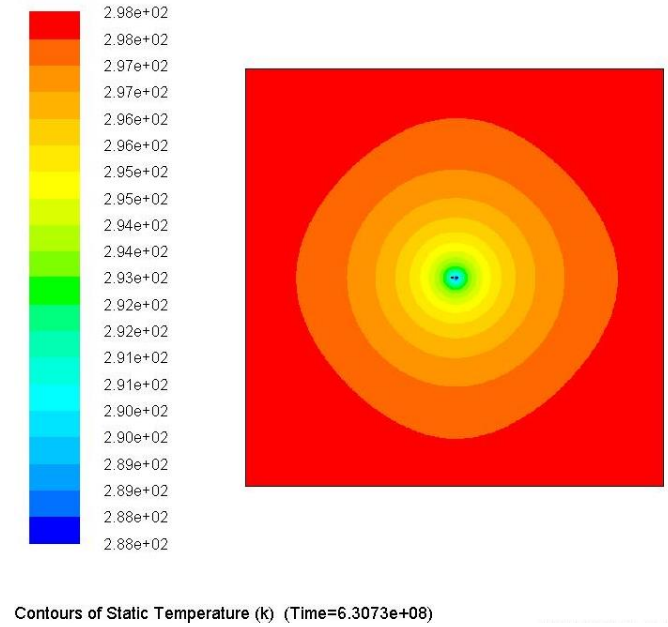



Figure 76: 20th Year Heating Seasons Temp Contour

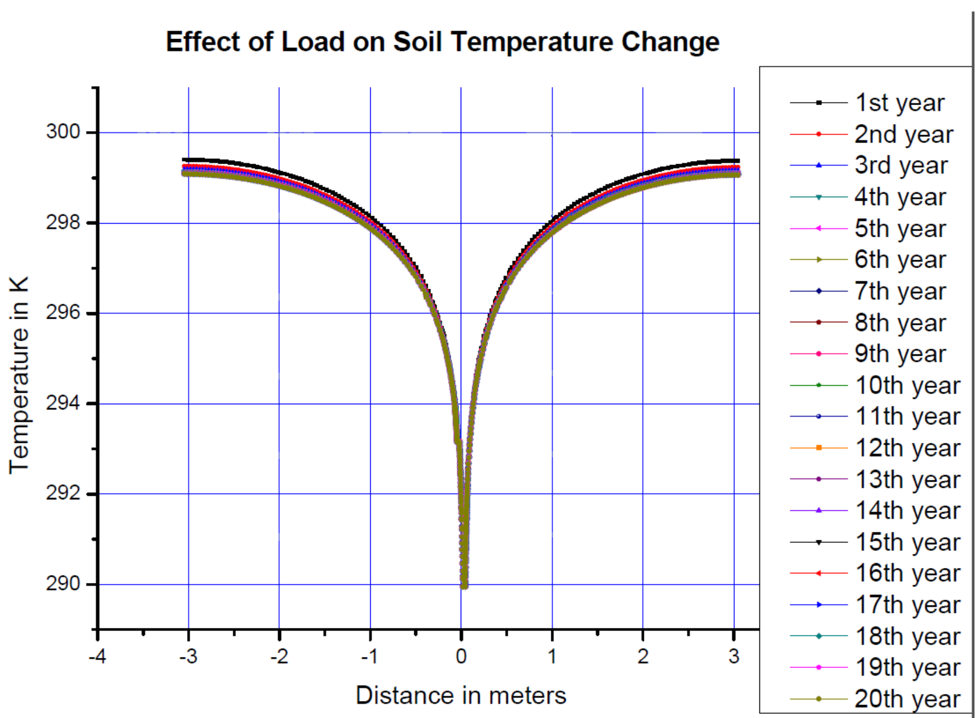



Figure 77: Soil Temperature Distribution of Red Line (Figure 30) for Effect of Load from 1st Year to 20th Year

Soil temperature change from initial year to 20th year for effect of load is -0.311 °C, eventually soil will cool down. Heat transfer rate is given below.

| Year | Heat Transfer Rate in Cooling season (MJ/season) | Heat Transfer Rate in Heating season (MJ/season) | Total Heat Transfer Rate (MJ/season) |
|---|---|---|---|
| 1st year | 134.018 | -129.983 | 4.022 |
| 2nd year | 140.454 | -127.697 | 12.756 |

As temperature of soil goes on decreasing after every year (year ends with heating season), ΔT will be increasing for cooling season. Thus, heat transfer rate increases for cooling season. In this case it is notable that temperature of soil goes on decreasing. This happens because maximum load (Maximum temperature difference between inlet and outlet of GLHE) during 2012 was considered for next 20 years of simulation during cooling season. Minimum load (Minimum temperature difference between inlet and outlet of GLHE) during 2012 was considered for next 20 year simulation for heating season, which is not possible practically. This study was conducted to find how much soil temperature will change if maximum load during cooling season and minimum load during heating season is considered for next 20 year, it is found that there will be change in -0.311 °C change in soil temperature.

### 6.3 Effect of Depth

### 6.3.1 Effect of Depth at 4ft

As 4ft depth is closer to ground surface, weather conditions affect this layer. Table 9 explains about boundary condition for this case. Following figures shows soil temperature distribution for 1st year, 5th year, 10th year and 20th year.

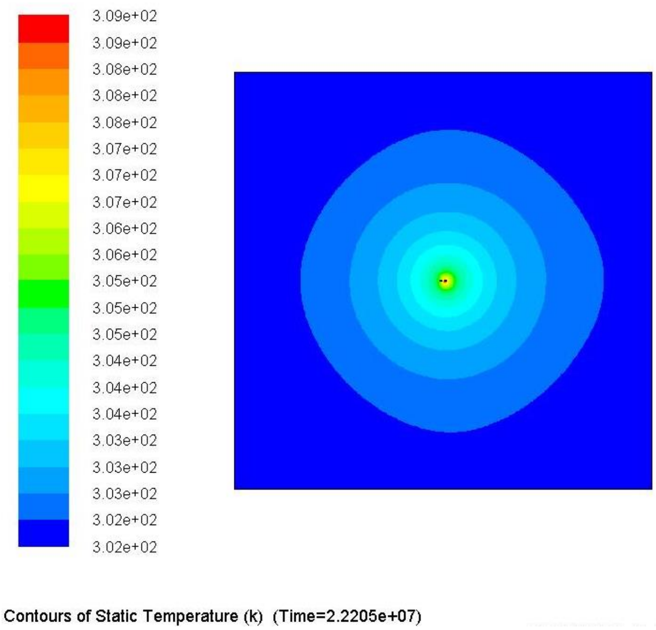



Figure 78: 1st Year Cooling Seasons Temp Contour

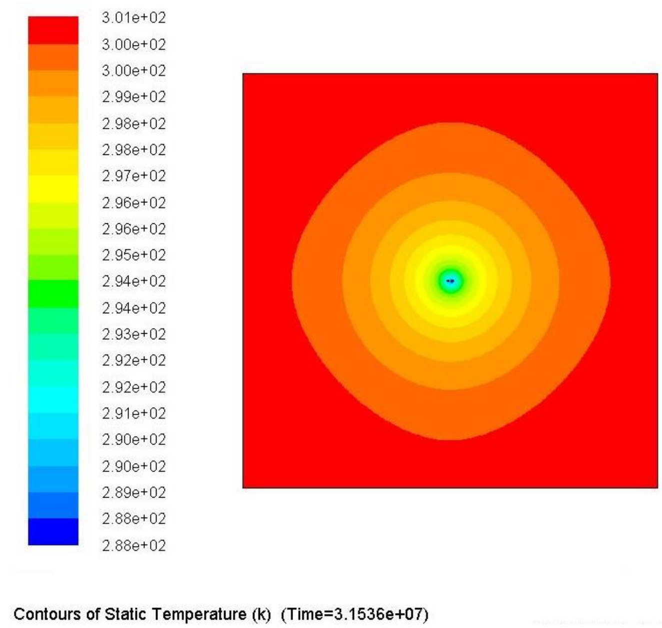



Figure 79: 1st Year Heating Season Temp Contour

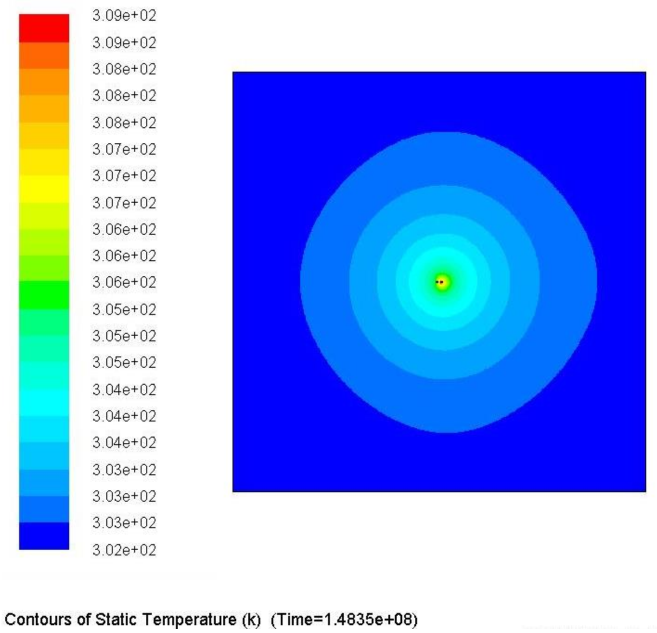



Figure 80: 5th Year Cooling Seasons Temp Contour

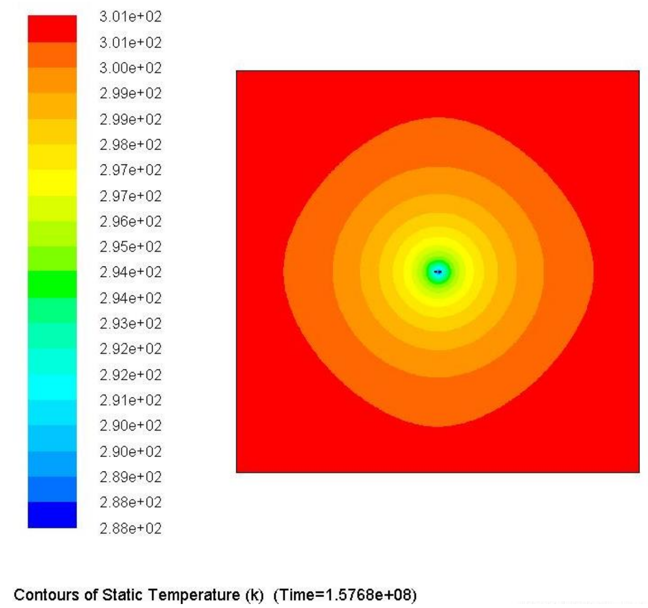



Figure 81: 5th Year Heating Seasons Temp Contour

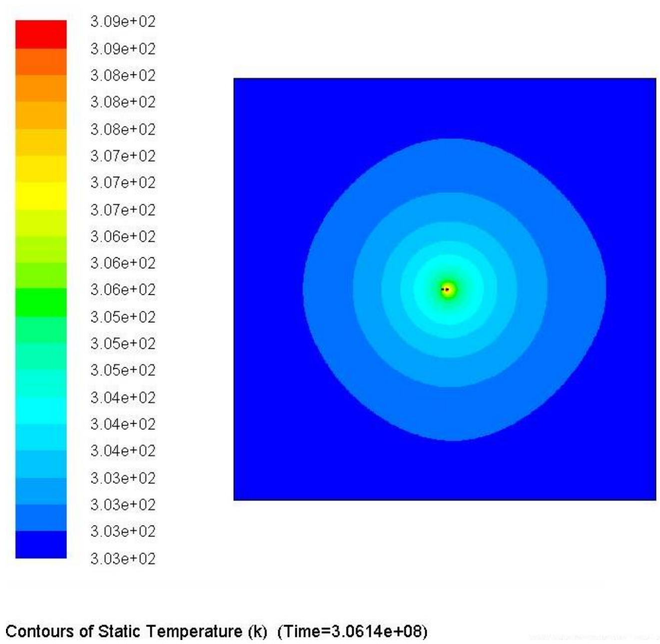



Figure 82: 10th Year Cooling Seasons Temp Contour

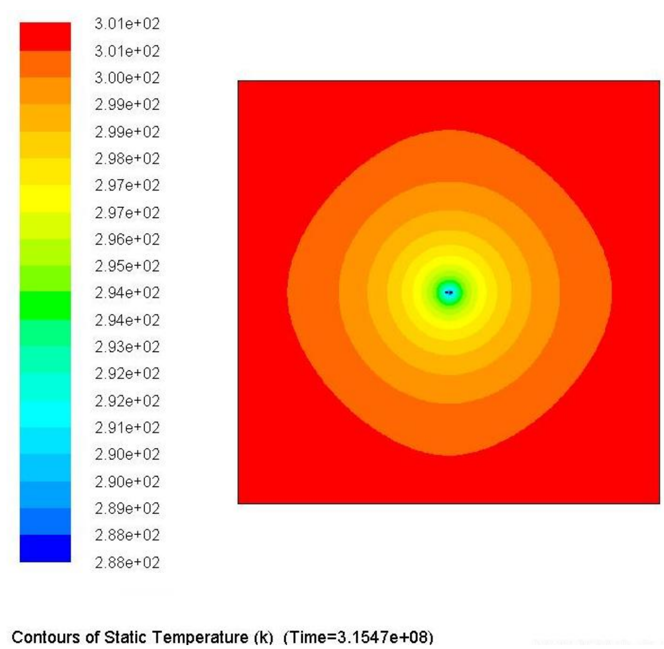



Figure 83: 10th Year Heating Seasons Temp Contour

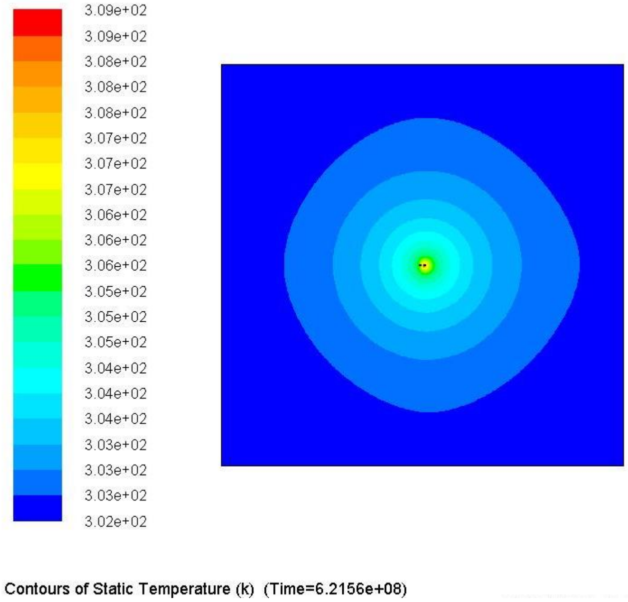



Figure 84: 20th Year Cooling Seasons Temp Contour

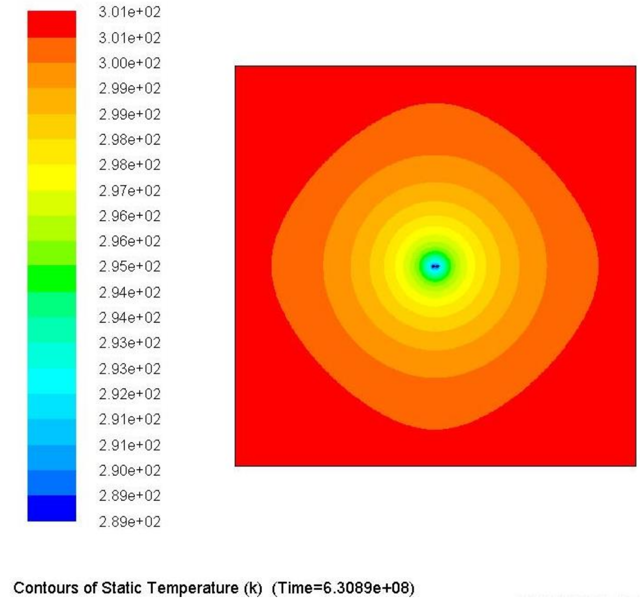



Figure 85: 20th Year Heating Seasons Temp Contour

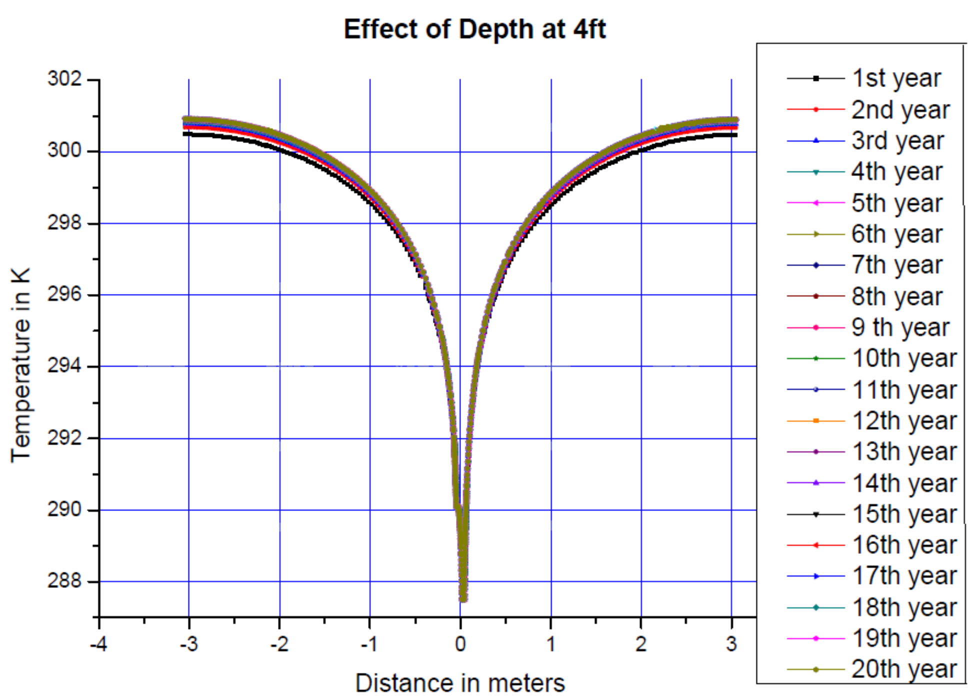



Figure 86: Soil Temperature Distribution along Red Line (Figure 30) for 1st Year to 20th Year at 4ft Depth

After 20th year simulation, soil temperature change between initial year and 20th year is 0.811 °C. Soil temperature will keep on increasing as year increases.

6.3.2 Effect of Depth at 6ft

After adding inputs from TAC VISTA readings for inlet and out temperature of GLHE and input from thermocouple readings from LABVIEW, simulation for 20 years was performed. Boundary conditions are specified in table 9. Figure 94 shows the soil temperature distribution along red line from 1st year heating season to 20th years heating season.

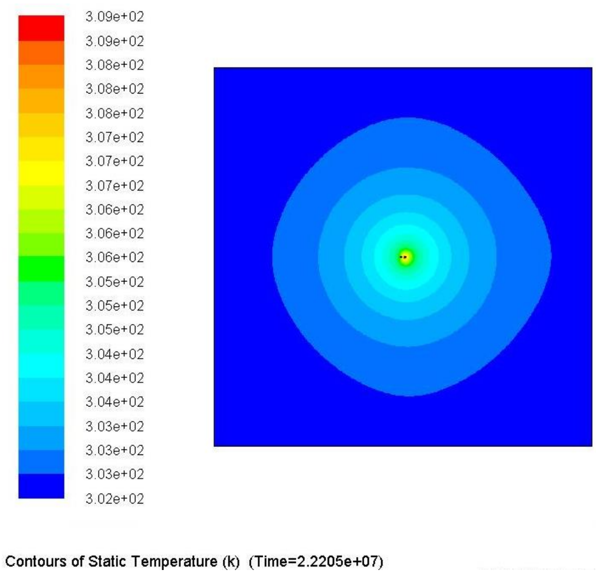



Figure 87: 1st Year Cooling Seasons Temp Contour

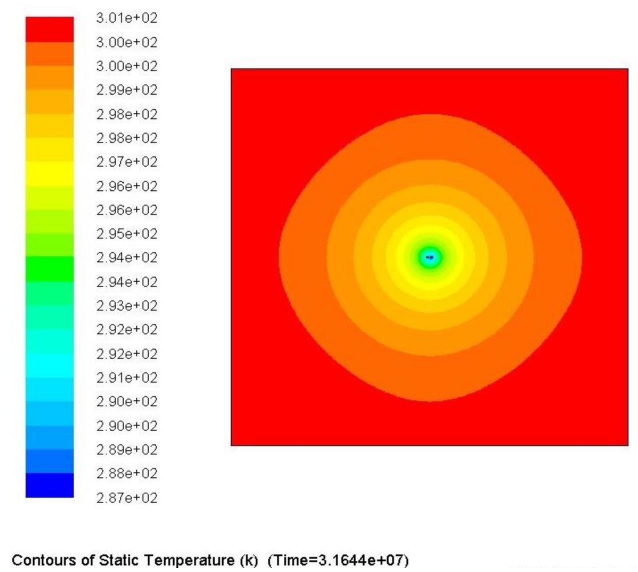



Figure 88: 1st Year Heating Season Temp Contour

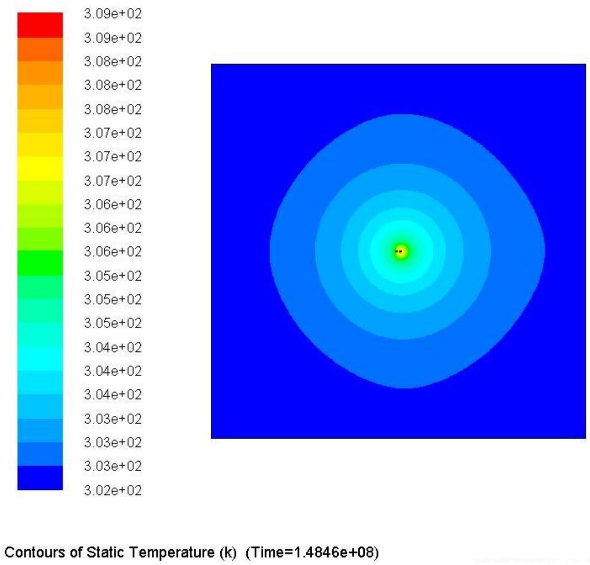



Figure 89: 5th Year Cooling Seasons Temp Contour

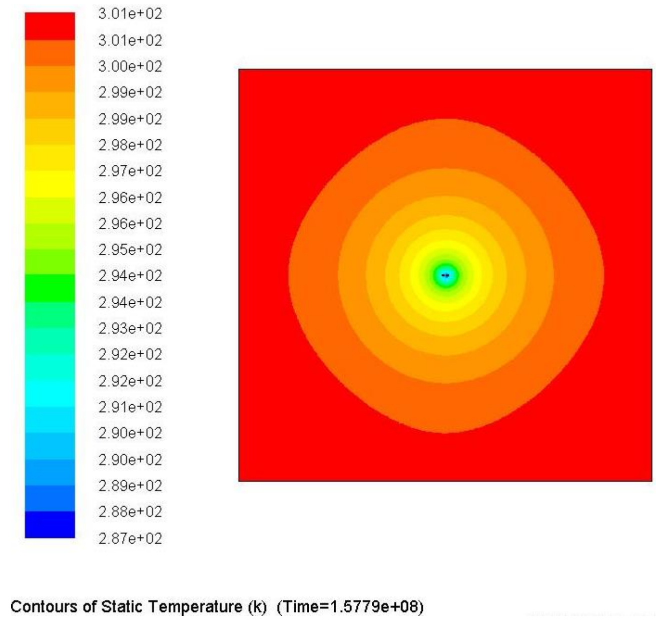



Figure 90: 5th Year Heating Seasons Temp Contour

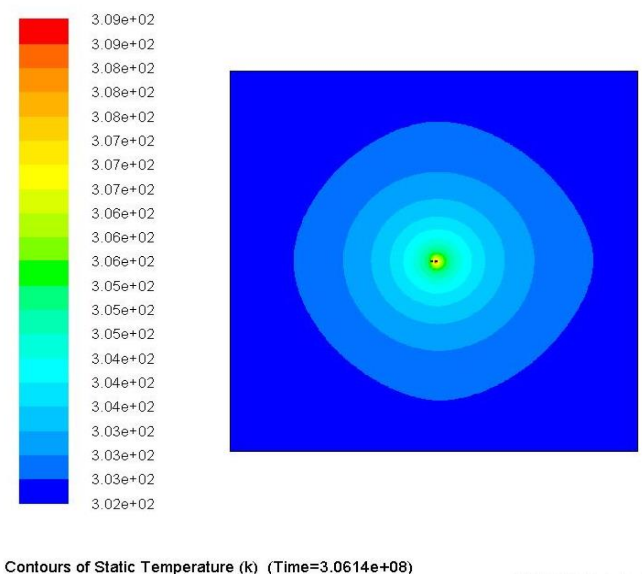



Figure 91: 10th Year Cooling Seasons Temp Contour

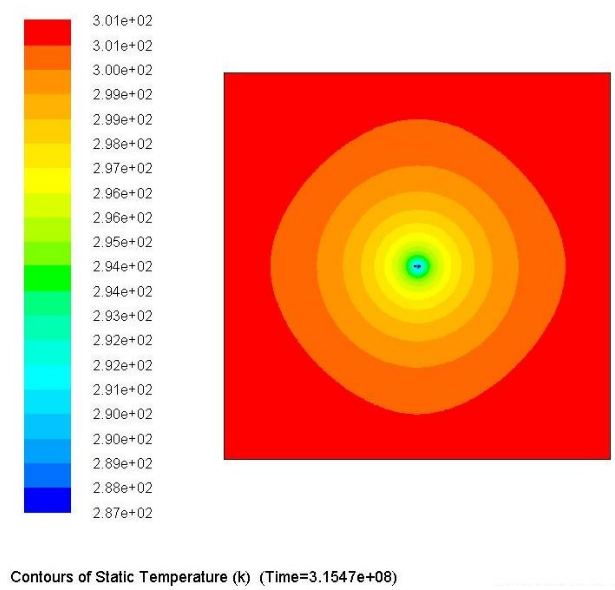



Figure 92: 10th Year Heating Seasons Temp Contour

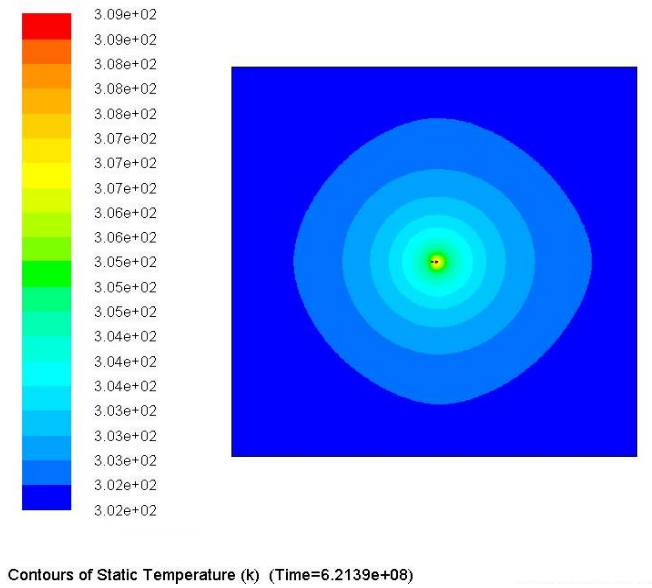



Figure 93: 20th Year Cooling Seasons Temp Contour

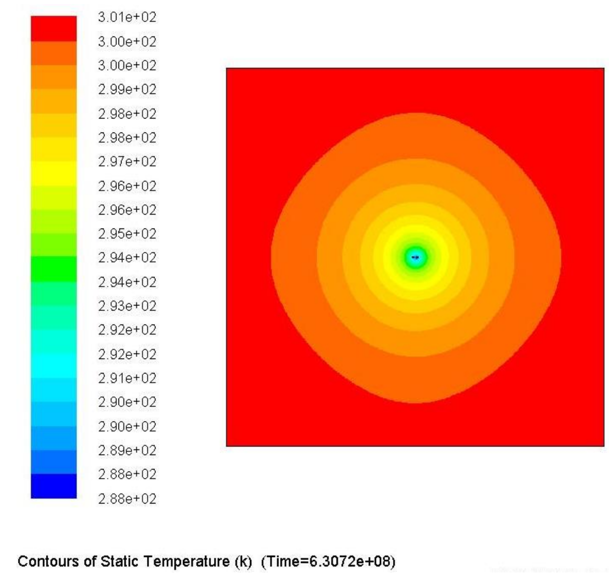



Figure 94: 20th Year Heating Seasons Temp Contour

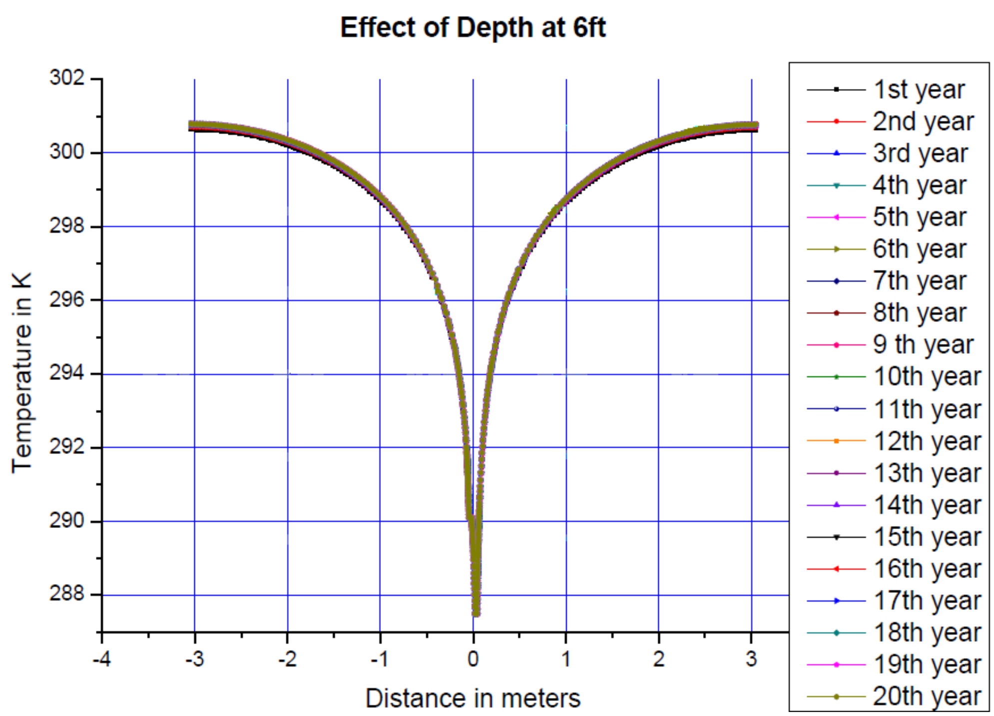



Figure 95: Soil Temperature Distribution along Red Line (Figure 30) from 1st Year to 20th Year at Depth of 6ft

As 6ft depth is affected by weather conditions, soil temperature change between initial year and 20th year is 1.051 °C.

6.3.3 Effect of Depth at 8 ft

Simulation in 6.1 and 6.2 are carried out at 8 ft depth. Effect of time for ZØE's heating and cooling season (6.1.4) has same boundary conditions like this case of effect of soil temperature change at depth of 8ft. The results for this case will be same as in 6.1.4.

6.3.4 Effect of Depth at 110 Ft

Following figures shows the soil temperature distribution for 1st year, 5th year, 10th year and 20th year. Figure 103 shows soil temperature distribution along red line (figure 30) from 1st year heating season to 20th year heating season.

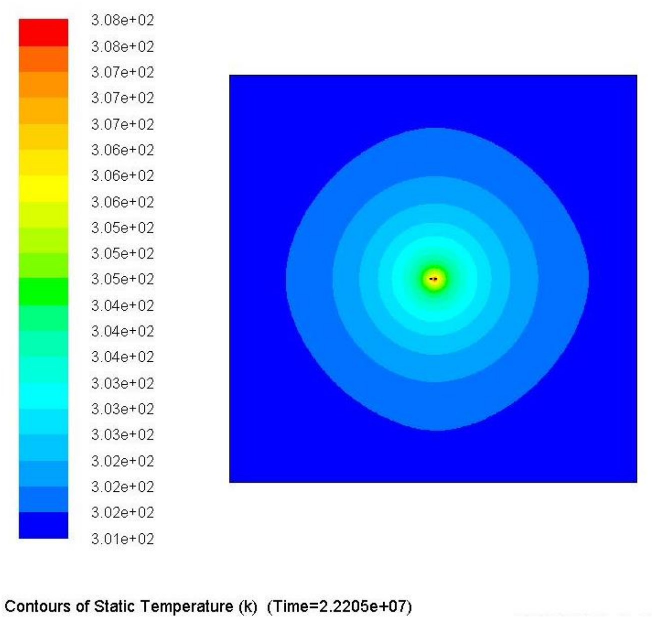



Figure 96: 1st Year Cooling Seasons Temp Contour

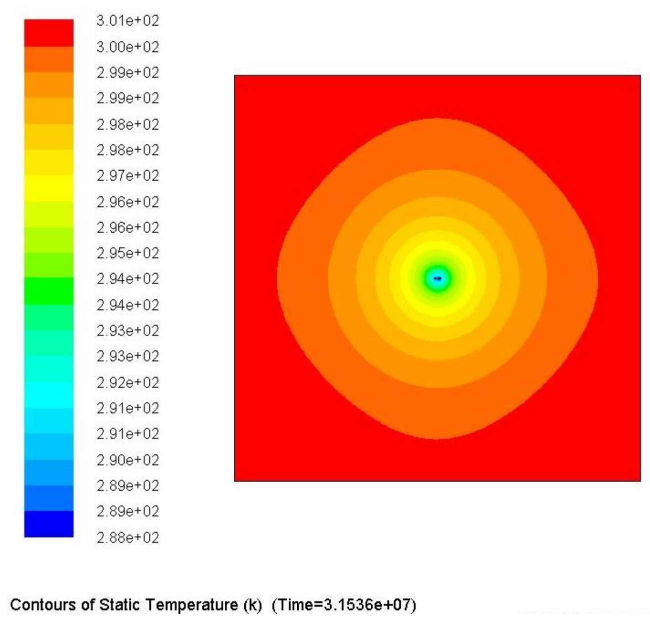



Figure 97: 1st Year Heating Seasons Temp Contour

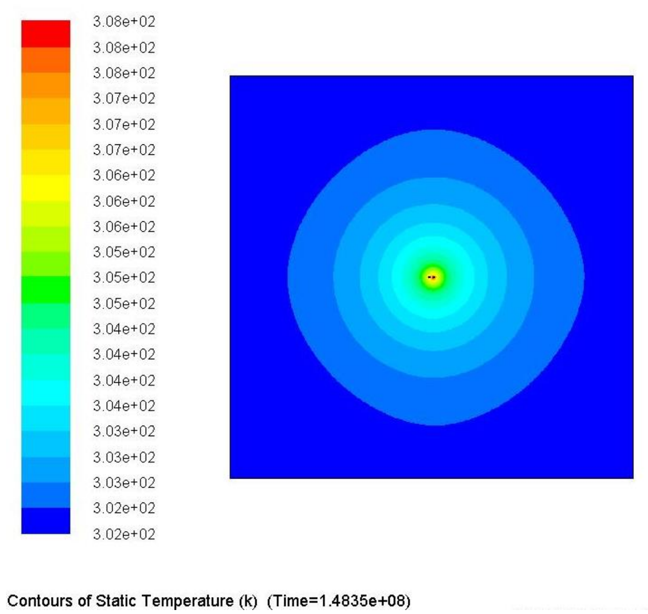



Figure 98: 5th Year Cooling Seasons Temp Contour

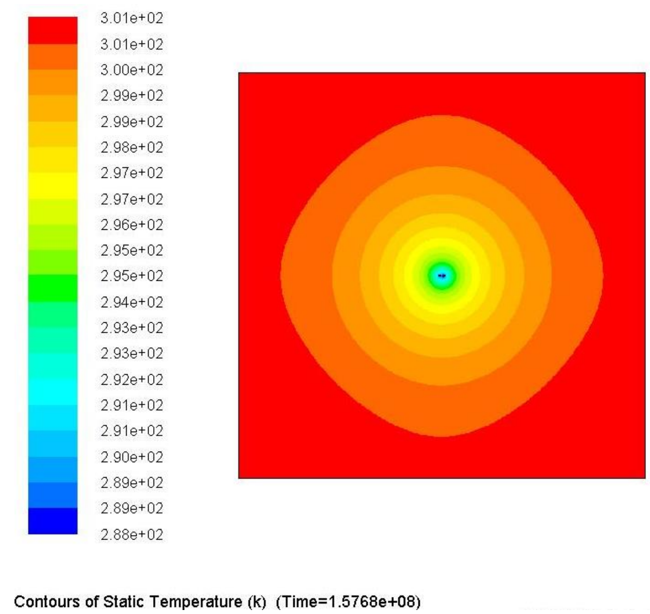



Figure 99: 5th Year Heating Seasons Temp Contour

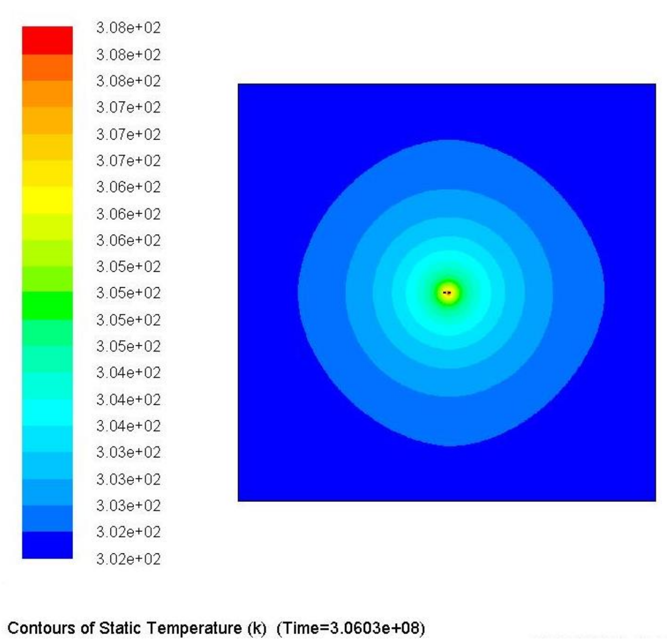



Figure 100: 10th Year Cooling Seasons Temp Contour

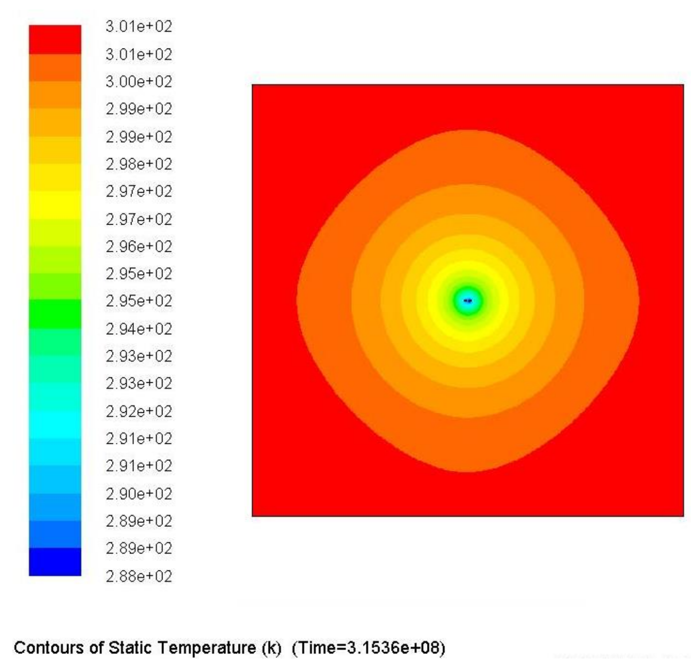



Figure 101: 10th Year Heating Seasons Temp Contour

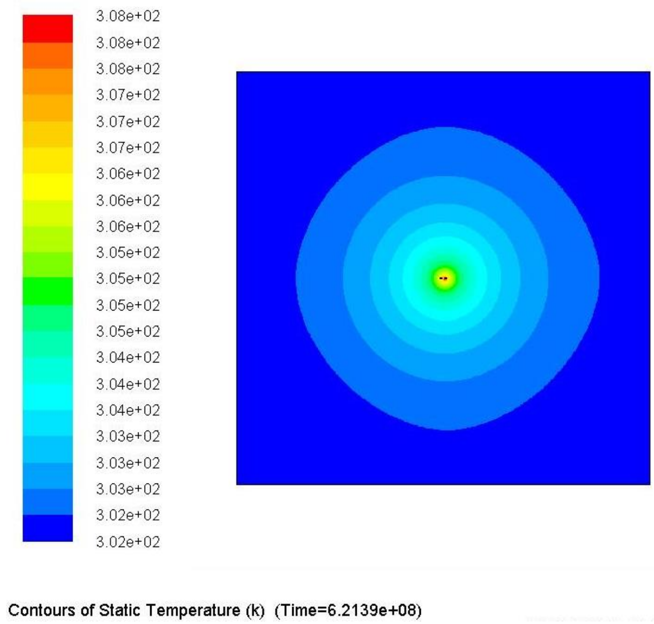



Figure 102: 20th Year Cooling Seasons Temp Contour

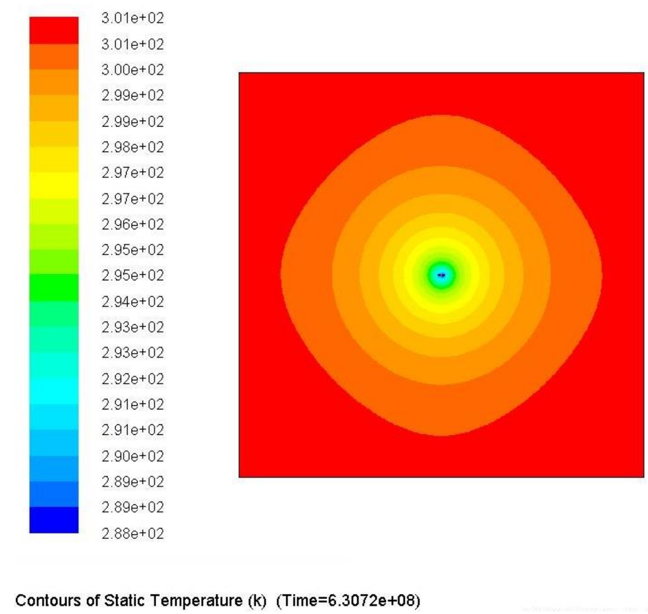



Figure 103: 20th Year Heating Season Temp Contour

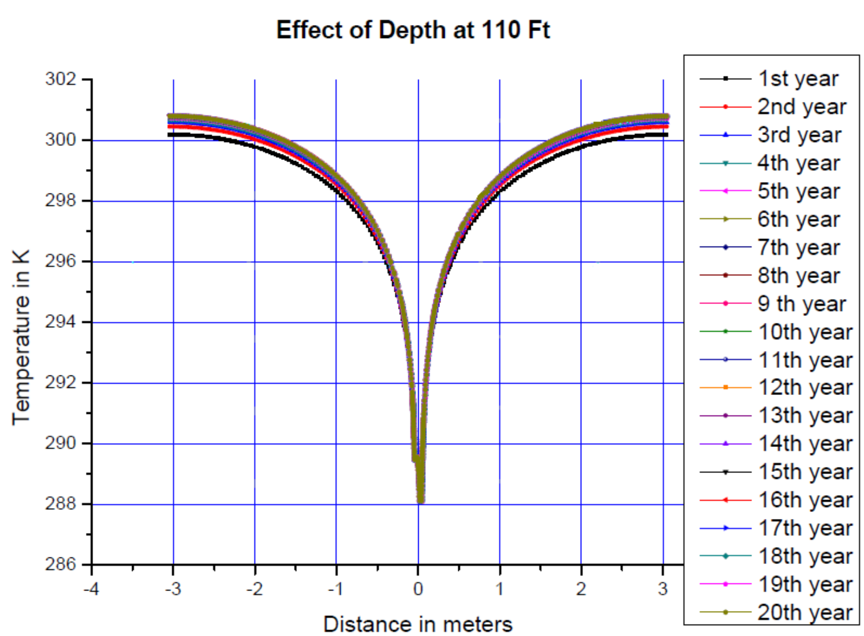



Figure 104: Soil Temperature Distribution along Red Line (Figure 30) from 1st Year to 20th Year at 110 Ft. Depth

After using boundary conditions and running simulation for 20 years, temperature difference between initial year and 20th year is 1.408 °C.

### 6.3.5 Effect of Depth at 220 ft

Following figures shows the soil temperature distribution for 1st year, 5th year, 10th year and 20th year. Figure 112 shows soil temperature distribution along red line (Figure 30) from 1st year heating season to 20th year heating season.

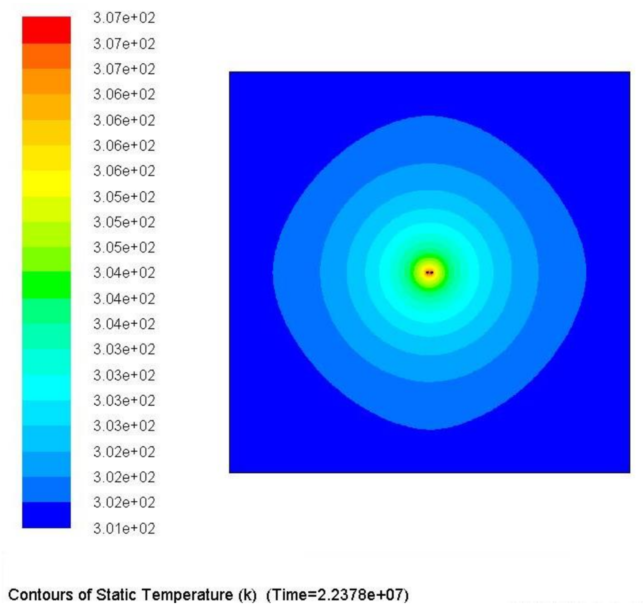



Figure 105: 1st Year Cooling Seasons Temp Contour

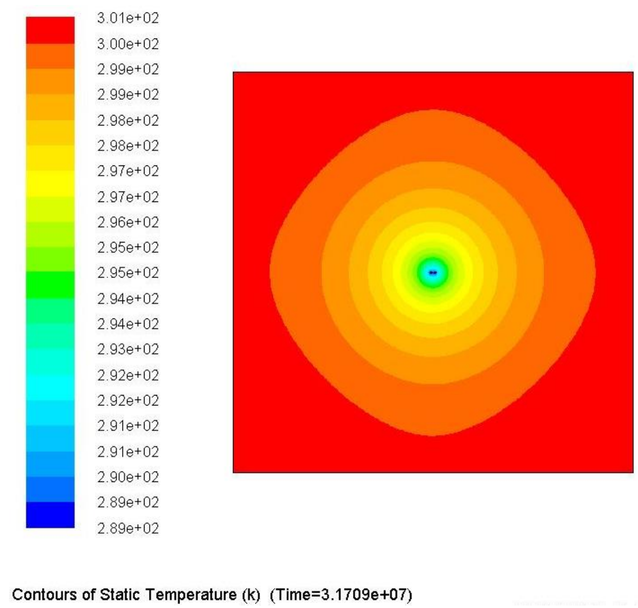



Figure 106: 1st Year Heating Seasons Temp Contour

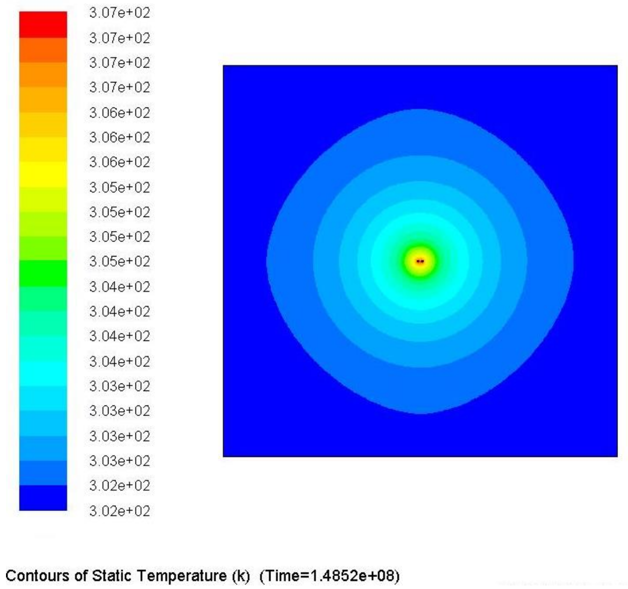



Figure 107: 5th Year Cooling Seasons Temp Contour

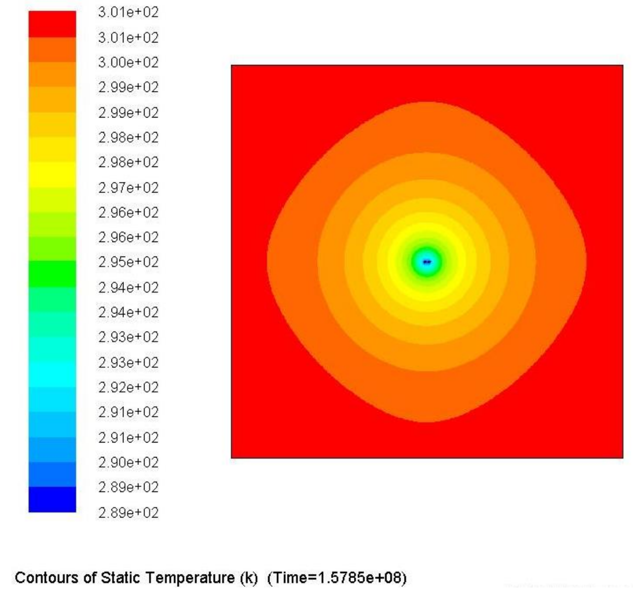



Figure 108: 5th Year Heating Seasons Temp Contour

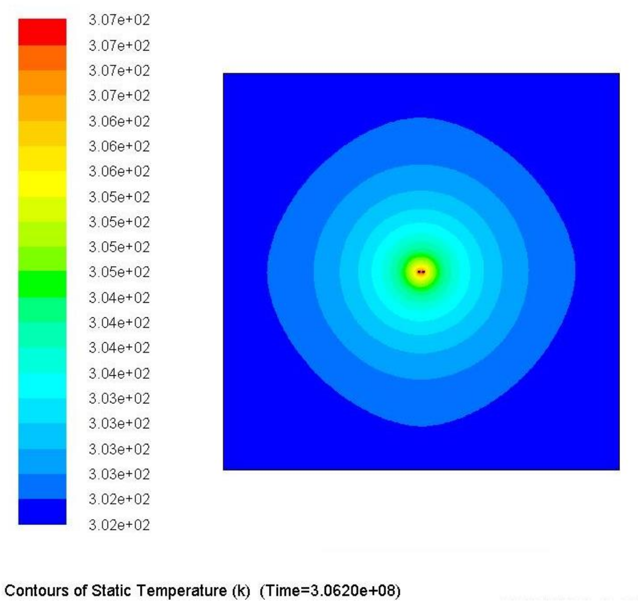



Figure 109: 10th Year Cooling Seasons Temp Contour

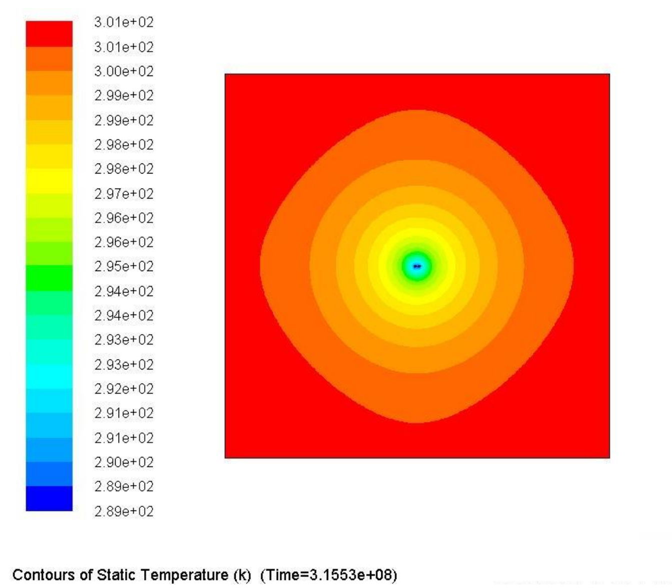



Figure 110: 10th Year Heating Seasons Temp Contour

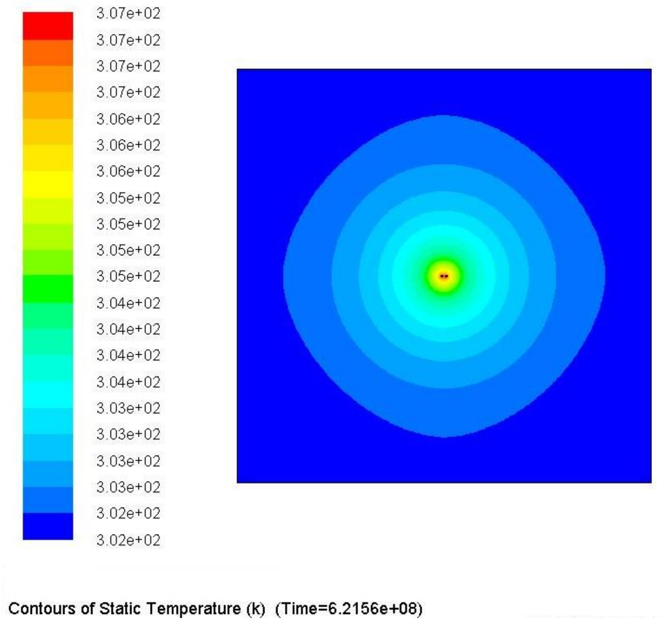



Figure 111: 20th Year Cooling Seasons Temp Contour

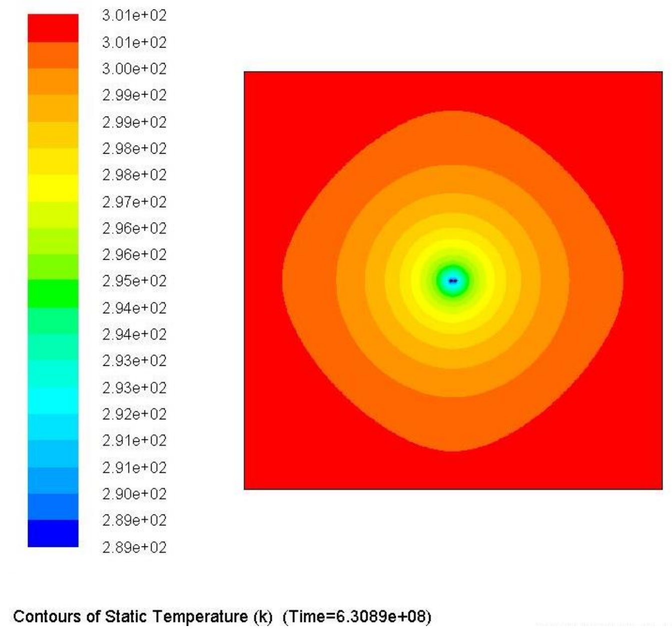



Figure 112: 20th Year Heating Seasons Temp Contour

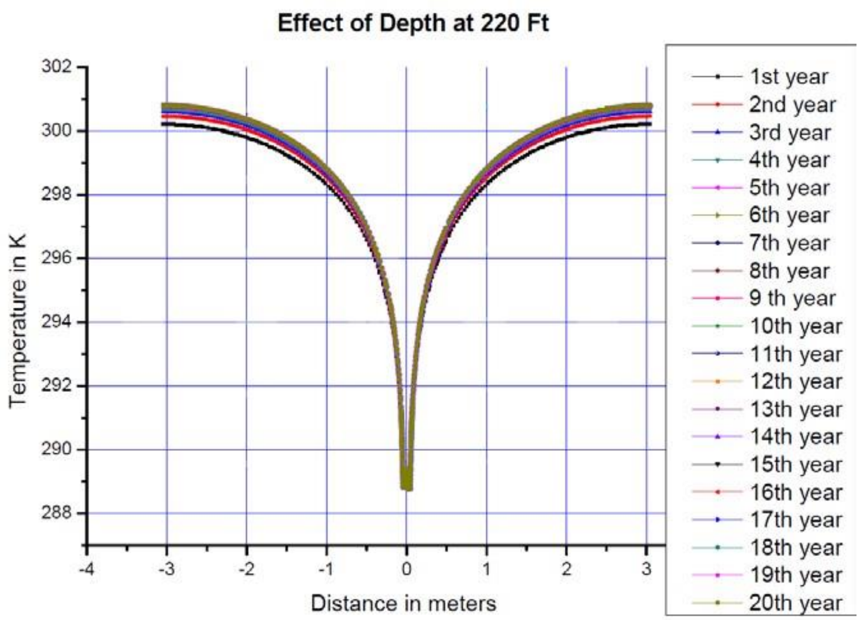



Figure 113: Soil Temperature Distribution along Red Line (Figure 30) from 1st Year to 20th Year at 220 Ft. Depth

Soil temperature difference between initial year and 20th year is 1.405 °C. Following table 12 gives conclusion about effect of depth for soil temperature change.

Table 12: Soil Temperature Change at Various Depths

| Depth (Ft) | Soil Density in $Kg/m^3$ | Initial Year Soil Temperature (°K) | Soil Temperature Change from Initial Year to $20^{th}$ Year (°K) |
|---|---|---|---|
| 4 | 1591 | 300.16 | 0.811 |
| 6 | 1570 | 299.74 | 1.051 |
| 8 | 1579.42 | 299.4 | 0.980 |
| 110 | 1839 | 299.4 | 1.408 |
| 220 | 1839 | 299.4 | 1.405 |

## 6.4 Effect of Doubling Temperature Difference between Inlet and Outlet of GLHE

A study was conducted to see soil temperature change after 20 years if temperature difference of inlet and outlet of GLHE of ZØE is doubled. Temperature difference of maximum and minimum load during cooling and heating season on ZØE during 2012 is doubled for this case, boundary conditions of this case is given in table 8. Figure 121 shows soil temperature distribution along red line (Figure 30) from 1st year heating season to 20th year heating season.

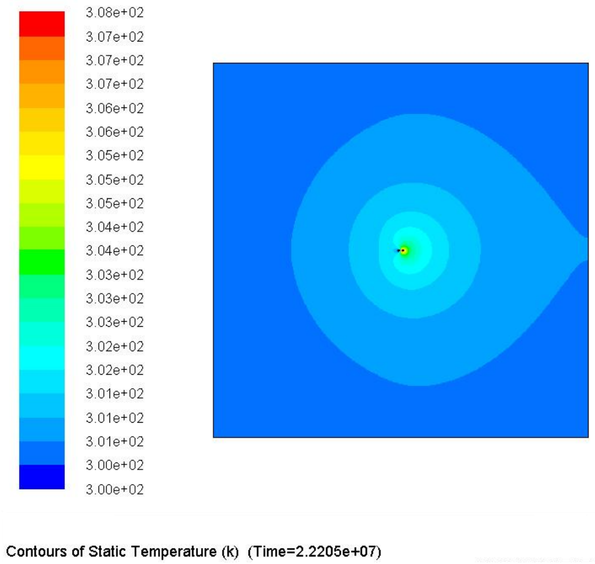



Figure 114: 1st Year Cooling Seasons Temp Contour

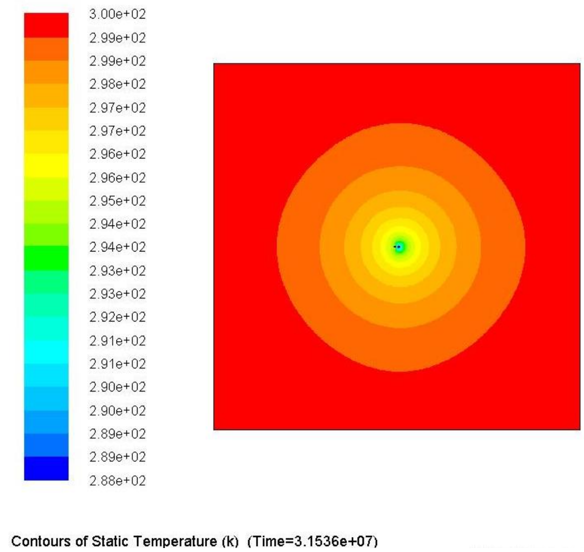



Figure 115: 1st Year Heating Seasons Temp Contour

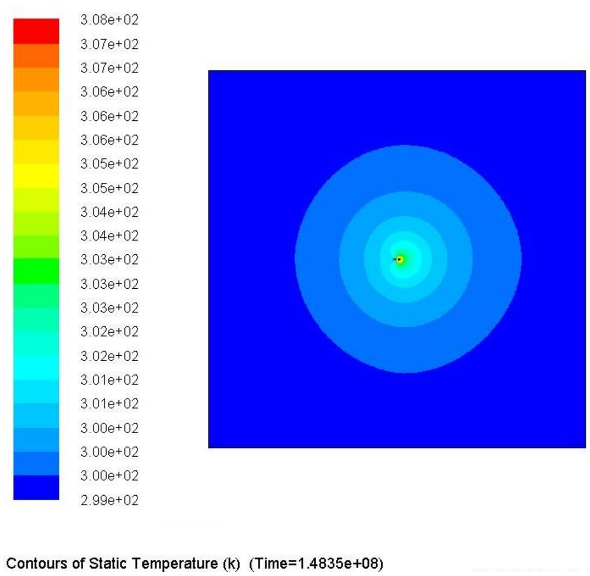



Figure 116: 5th Year Cooling Seasons Temp Contour

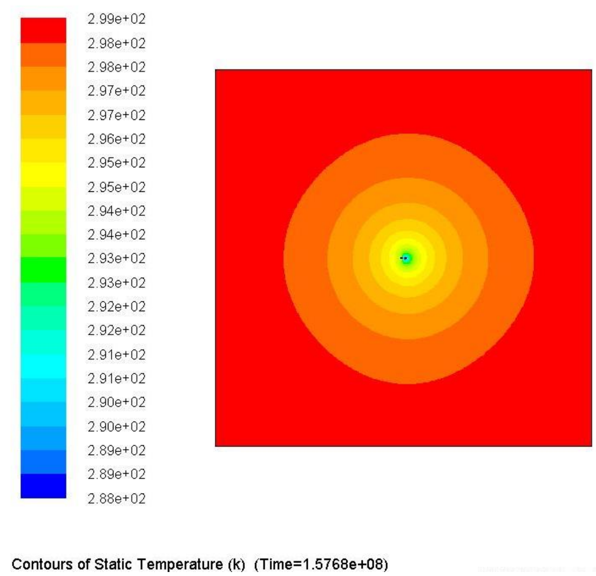



Figure 117: 5th Year Heating Seasons Temp Contour

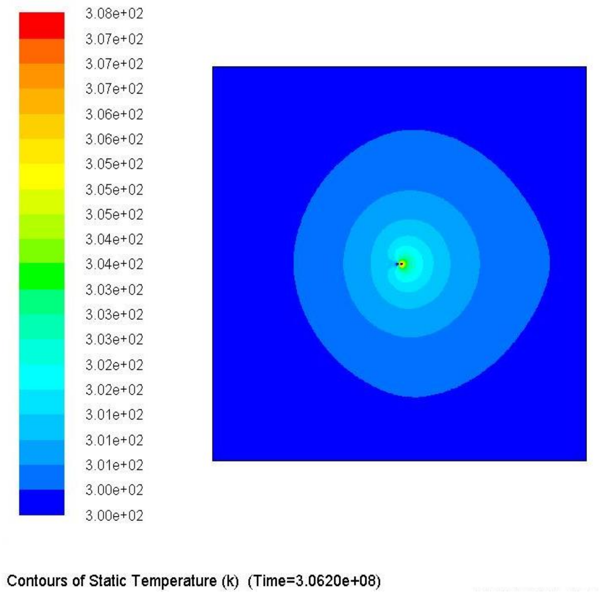



Figure 118: 10th Year Cooling Seasons Temp Contour

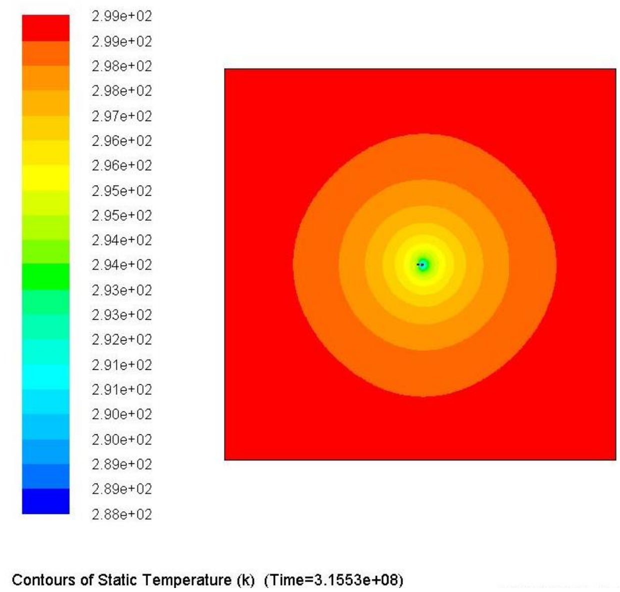



Figure 119: 10th Year Heating Seasons Temp Contour

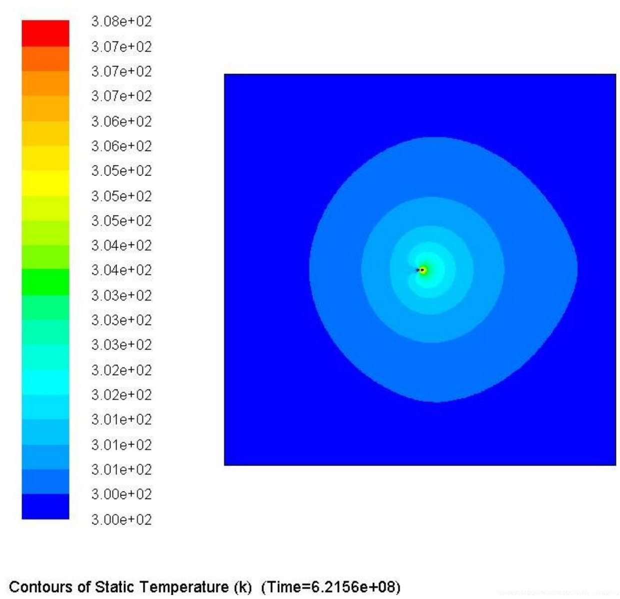



Figure 120: 20th Year Cooling Seasons Temp Contour

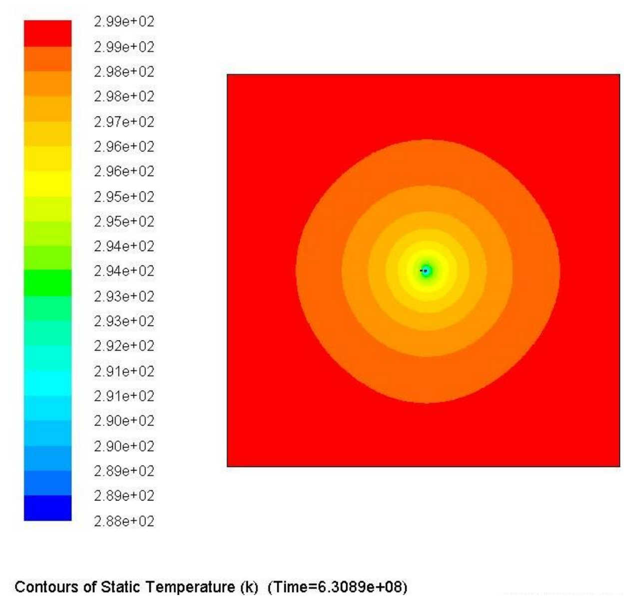



Figure 121: 20th Year Heating Seasons Temp Contour

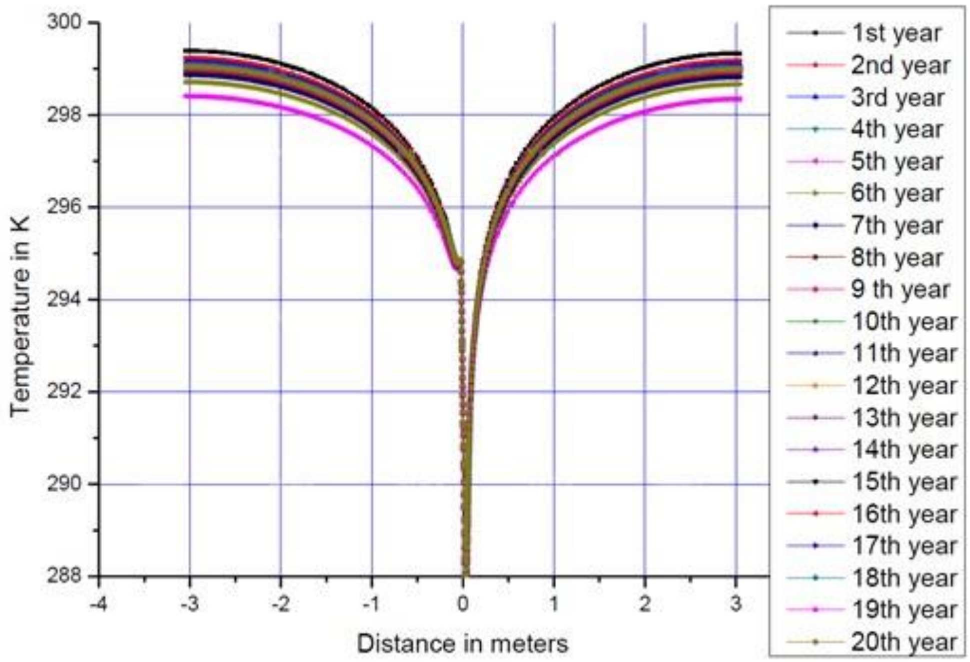



Figure 122: Soil Temperature Distribution along Red Line (Figure 30) from 1st Year to 20th Year for Effect of Doubling ΔT of GLHE

Soil temperature change from initial year to 20th year is -0.911 °C. Heat transfer rate for 1st and 2nd year is shown below.

| Year | Heat Transfer Rate in Cooling Season (MJ/season) | Heat Transfer Rate in Heating Season (MJ/season) | Total Heat Transfer Rate (MJ/season) |
|---|---|---|---|
| 1st year | 120.461 | 139.688 | -19.227 |
| 2nd year | 115.825 | 140.901 | -25.080 |

Eventually soil will cool down. This case was studied to know soil temperature change when ΔT between input and output of GLHE is doubled. By considering maximum load during cooling season and minimum load during heating season of 2012 and doubling this temperature, ΔT temperature difference was considered for next 20 years simulation. This is not practically possible for GLHE. Thus, thermal transient results shows that there is -0.911 °C soil temperature change from initial year to 20th year.

6.5 Soil Temperature Change, If Same ZØE Present in Miami, Florida

A simulation was conducted to find soil temperature change, if same ZØE is present in Miami, Florida. Same load of ZØE in Denton, TX is considered for this case. Numbers of heating and cooling equivalent days in Miami, Florida were 305 cooling season days, 33.5 heating season days and 26.3 days for transition period from September 2012 to August 2013 [13]. Following figure shows soil temperature distribution from 1st year, 5th year, 10th year and 20th year.

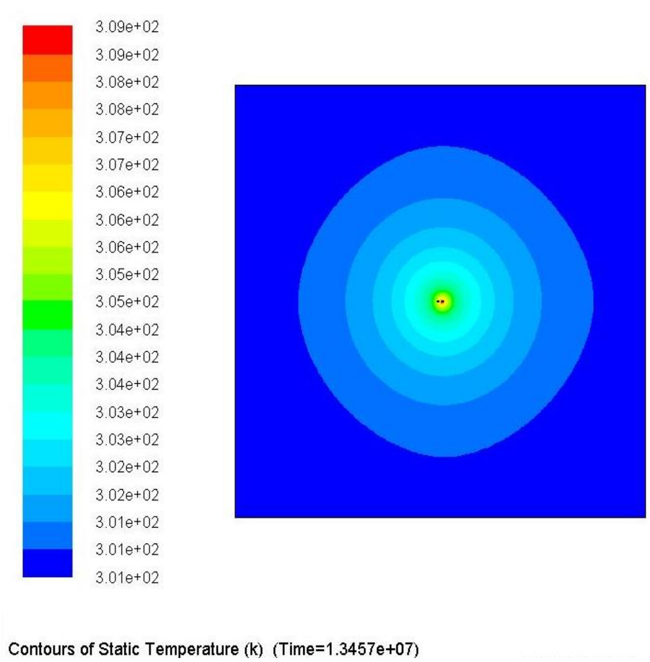



Figure 123: 1st Year Cooling Seasons Temp Contour

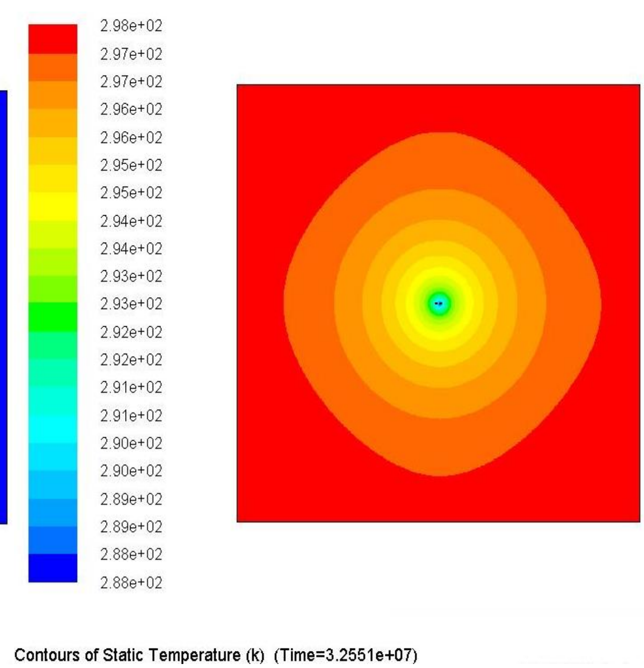



Figure 124: 1st Year Heating Seasons Temp Contour

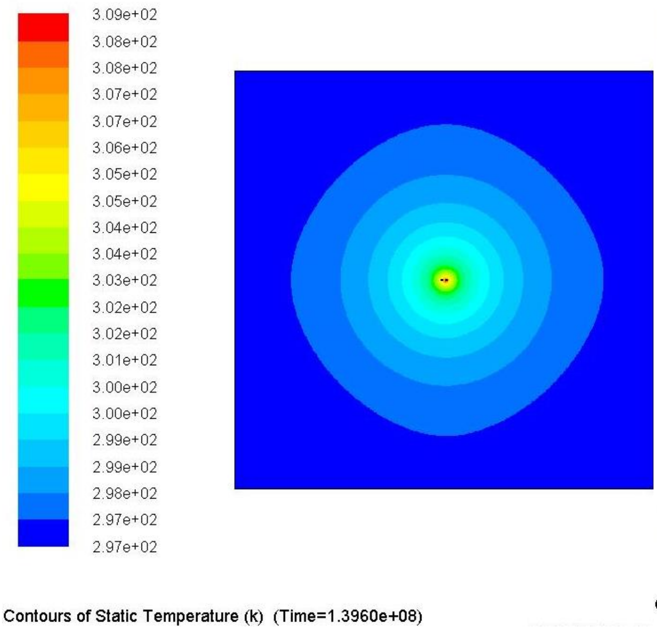



Figure 125: 5th Year Cooling Season Temp Contour

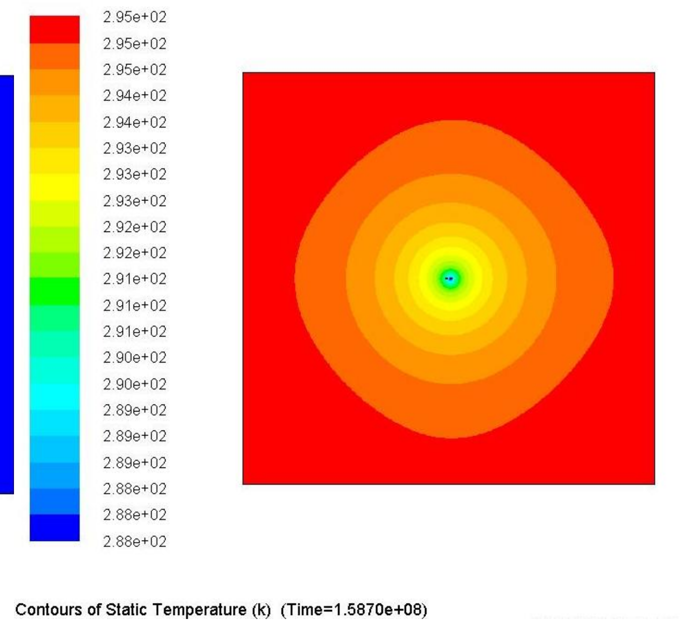



Figure 126: 5th Year Heating Seasons Temp Contour

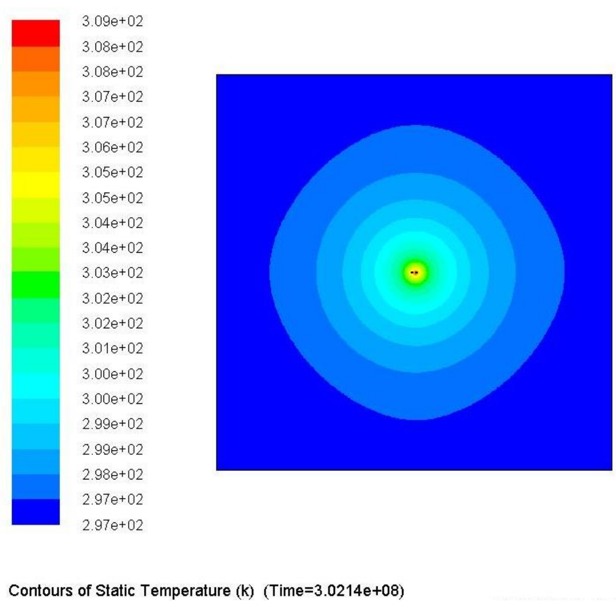



Figure 127: 10th Year Cooling Seasons Temp Contour

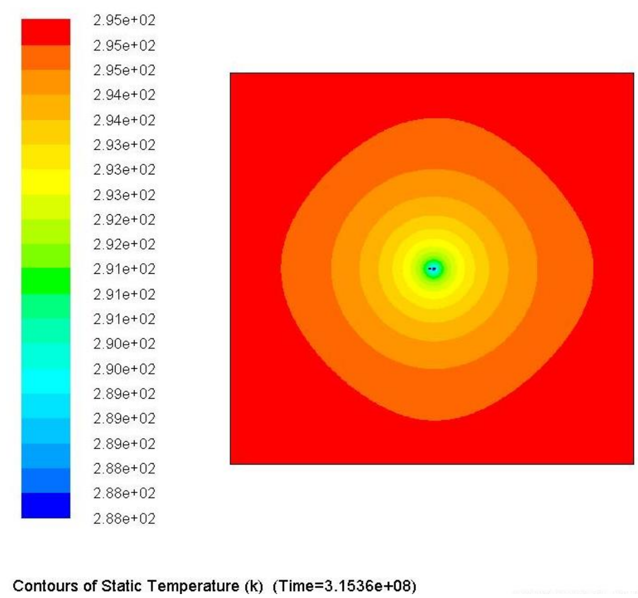



Figure 128: 10th Year Heating Seasons Temp Contour

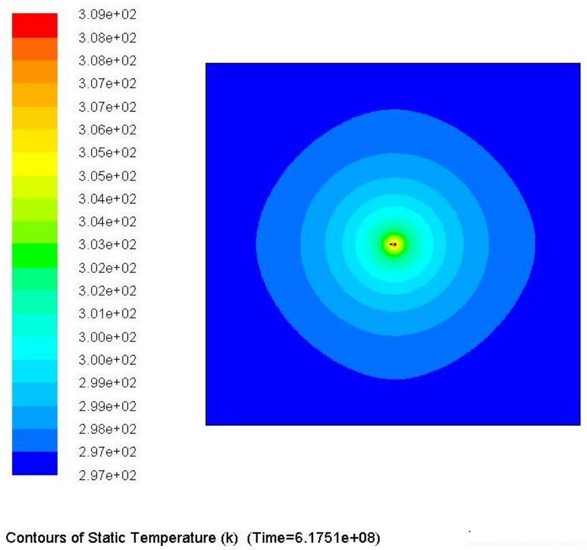



Figure 129: 20th Year Cooling Seasons Temp Contour

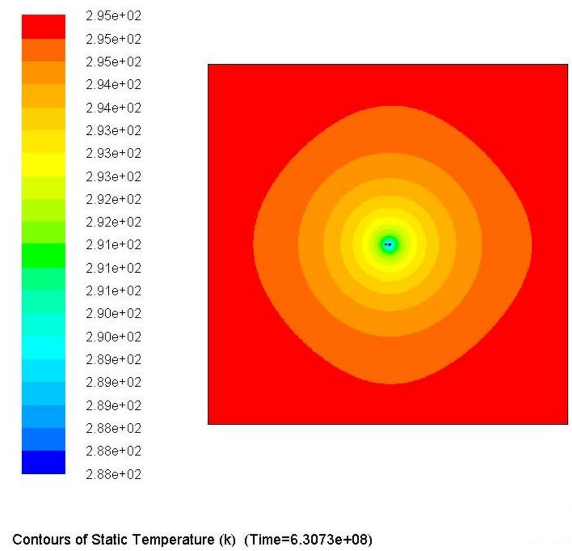



Figure 130: 20th Year Heating Seasons Temp Contour

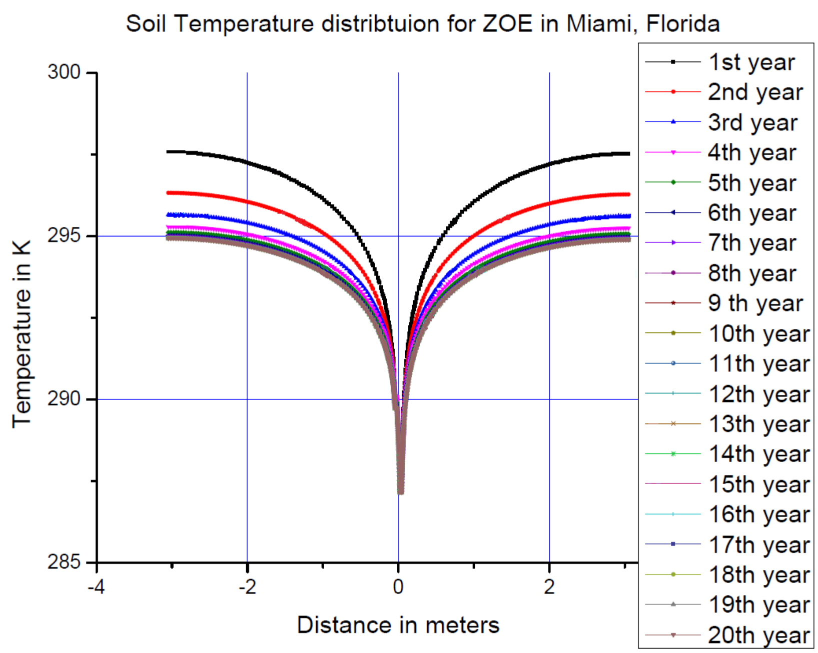



Figure 131: Soil Temperature Distribution along Red Line (Figure 30) for Same ZØE at Miami, Florida

After 20 year simulation, soil temperature change for ZØE in Miami, Florida will be 5.030° C. This is because of reason that cooling seasons are too long as compared to heating season. Cooling season is 10.16 month/year and heating season is 1.4month/year. Thus, heat will be added to soil continuously. Heat transfer rate for ZØE in Miami, Florida shown below,

| Year | Heat Transfer Rate In Cooling Season (MJ/season) | Heat Transfer Rate In Heating Season (MJ/season) | Total Heat Transfer Rate (MJ/season) |
|---|---|---|---|
| 1st year | 206.114 | -55.996 | 150.118 |
| 2nd year | 160.030 | -60.833 | 99.197 |

Heat transfer rate goes on decreasing as year passes. As in this case there are more number of cooling season days, so soil will eventually heat up and COP of GSHP will decrease.

# CHAPTER 7

# CONCLUSION

Due to long cooling or heating season, there is continuous addition or rejection of heat to the ground. For longer cooling season case, continuous addition of heat to the ground will heat up soil and eventually as year passes a stage will come when temperature difference between GLHE and soil will be same. Thus, there will be no heat transfer between GLHE and soil. Working fluid will not cool up which affects HVAC performance of building. ZØE is self-sustainable building. Ground Heat is only source of energy for running HVAC of ZØE. Therefore, it is very important to know soil temperature change over the years, which affects HVAC of ZØE.

A 2D transient thermal analysis was conducted for cross section of single GLHE for soil temperature change over 20 year. Simulation was conducted for the effect of various time period of cooling and heating season, effect of load, effect of depth, effect of doubling ΔT of GLHE and same ZØE if present in Miami, Florida.

For effect of time, soil temperature difference for 7-5month, 6-4month, 7-3 month and ZØE cooling and heating day from Initial year to 20$^{th}$ year is -1.420 °C, -0.798 °C, 1.137 °C and 0.988 °C. For fourth case at 8ft of depth, heat is not balance as after first year there will be 13.421 MJ/year heat will be added next year. By considering maximum and minimum temperature of Denton during 2012, it will take 135.32 year to heat up soil and no heat transfer takes place.

For effect of Load, soil temperature difference between initial and 20$^{th}$ year is -0.311 °C. Heat is not balance in this case, as there will be 4.003 MJ/year of heat will be added first year and goes on reducing for next 20 years. It is notable that soil temperature goes on decreasing as year passes because of reason that maximum load during cooling season and minimum load during heating season is considered for next 20 year simulation, which is not possible practically.

For effect of doubling ΔT of GLHE, soil temperature difference will be -0.994 °C. Heat is not balance in this case, unbalanced heat is -19.227MJ/year. From this case it can be concluded that, there can be heat balance if more heat can be used during heating season. For example more usage of hot water during winter can balance heat.

At depth of 4ft, 6ft, 8ft, 110ft and 220ft initial year's soil temperature are 300.16 °K, 299.74 °K, 299.4°K, 299.4 °K and 299.4°K. After simulating it for 20 years soil temperature difference between initial year and 20$^{th}$ year varies as 0.811 °C, 1.051°C, .980 °C, 1.408°C and 1.405 °C.

If same ZØE of Denton built in Miami Florida, soil temperature change from initial year to 20$^{th}$ year is 5.030 °C. Because of 10.15 month/year cooling season, heat will be continuously added to ground, due to less number of heating season days heat will not balance and soil temperature will keep on increasing. Unbalanced heat is 150.118 MJ/year. For ZØE in Miami, Florida, to balance heat or to reduce heating of soil every year in winter season same ground heat can be used for some other purposes which were not part of load for GLHE previously. To balance heat, excess ground heat for heating of swimming pool in winter.

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