Thermosyphon in End View

1 Introduction

Thermosyphons and heat pipes are a passive form of artificial ground freezing in which heat is transferred within a closed pipe due to a temperature difference at the ends of the pipe. This difference produces a density change and phase change of the fluid in the pipe or in a coupled heat exchanger. The term "thermosyphon" typically refers to devices in which the fluid phase change occurs within the pipe, yielding a density change of the fluid and a natural cycling process. Thermosyphons are used in arctic climates to harness cold weather to maintain frozen conditions in the soil – be it a road way or a frozen core dam. A "heat pipe" is a more common term for a mechanical system that is coupled with a heat exchanger to cool or heat buildings using constant ground temperatures at depth relative to hot or cold air temperatures near surface.

The objective of this analysis, along with the related example entitled 'Thermosyphon in Side View' is to determine if a permafrost zone can be maintained beneath a heated building for an average climate year. The example also demonstrates the use of cycling climate to establish a long-term thermal regime.

2 Feature highlights

GeoStudio feature highlights include:

- Transient 2D freezing
- Thermosyphon heat transfer boundary condition for freeze pipes
- Animation of freezing process

3 Geometry and Boundary Conditions

Figure 1 presents the model domain and a schematic of the building and thermosyphons installed in the foundation soil. The left edge of the domain represents the line of symmetry. The thermosyphon pipes extend into the page and angle up to the ground surface where their radiators are exposed to the climate. The model is two dimensional; so, numerically we are only considering the plane where the ends of the thermosyphon intersect the front of the drawing. The intent of the sketch is to show the number of pipes installed in the field and to highlight the end view of the pipes. A different TEMP/W example is used to analyze a thermosyphon in axisymmetric coordinates, which is a pseudo three-dimensional approach.

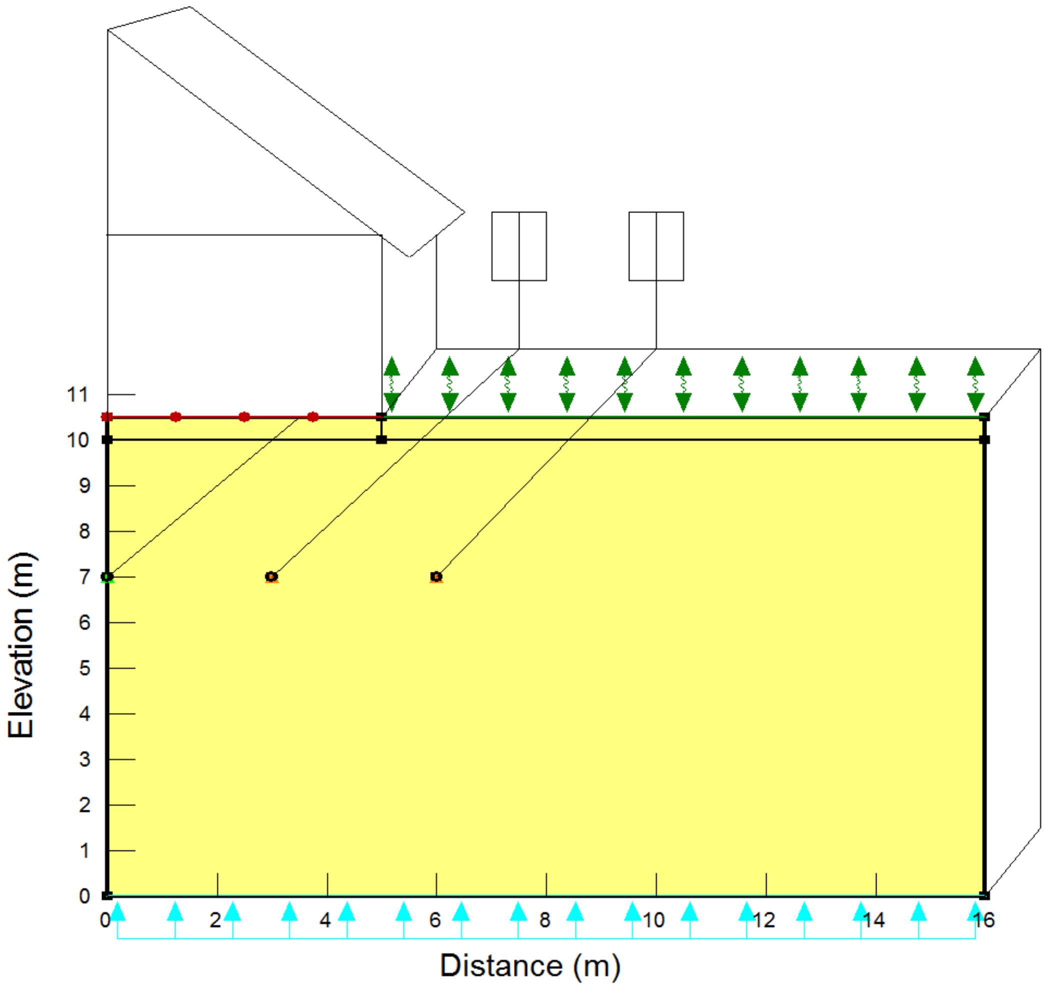


Figure 1 - Model domain and schematic of house and thermosyphons

There are several different boundary conditions applied in this analysis. The exposed ground surface uses a climate boundary condition with data for Fairbanks Alaska. The same windspeed and air temperature data in the climate data set is used for the thermosyphon climate heat loss calculations. There is a thermal temperature boundary condition that represents the warm ground beneath the base of the building. There is also an assumed constant temperature at depth in the permafrost along the base of the mesh. Finally, there is the thermosyphon boundary condition object.

The details of how a thermosyphon removes heat from the ground and gives it up to the atmosphere are discussed in the TEMP/W Engineering book as well as on many web sites. In the TEMP/W model, you create a thermosyphon object with various properties and then you apply it to a geometry point or line. If you apply it to a point, then the model is assuming the pipe intersects the soil normal to the plane of the mesh. The heat is extracted from the pipe at a rate that depends on the difference between the ground temperature and the air temperature and wind speed. You are required to enter information about the overall pipe length, the radiator size exposed to climate, and the maximum difference between air and ground temperature in order for the phase change of the gas in the pipe to be initiated. The following inputs are used in the analysis:

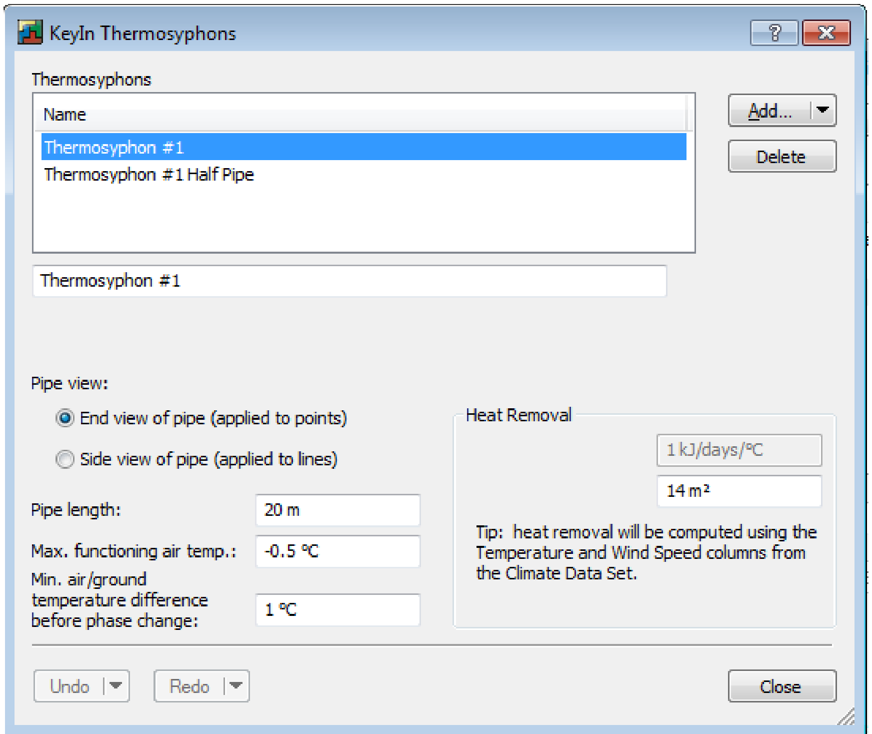


Figure 2 - Input parameters for thermosyphons

It is noted that there are two thermosyphon boundary conditions used in this analysis. The second accounts for half of the pipe at the line of symmetry by reducing the radiator area by half. The pipe length represents the total length of the pipe in the out-of-plane direction. It is used such that the overall heat removed by the surface radiator is divided by the length of the pipe and then applied per unit thickness of the model. You are also required to enter a heat removal rate for the radiator section at the top of each thermosyphon. There are two options. Firstly, specify the radiator size and then the heat transfer to the atmosphere is based on an empirical formula that uses the wind speed and air temperature data from the climate data set. The second option is to enter a heat removal rate that will only consider the difference between air and ground temperatures down the pipe at the modeled elevation.

Once the thermosyphon dataset is created, it can be assigned to any geometry point in the model. Specific points can be added at a desired location by clicking on the Draw Points command and then clicking on the model at the appropriate location. The model will regenerate the mesh to accommodate the new point. You can then assign the BC to that point using the Draw BC command.

There are three other boundary conditions in this model; a climate boundary, the inside building temperature boundary, and the base permafrost temperature boundary. The building temperature is assumed constant year round at a value of 15 C. The base of the model is assumed to be in the permafrost with a constant base geothermal heat gradient equal to a heat input of 8 KJ/day/meter.

The climate boundary condition is based on a full year of climate data for Fairbanks Alaska with the air temperatures adjusted to be 5 degrees colder to reflect a slightly more northern location. The climate data is repeated automatically if the duration of the analysis exceeds the duration of the analysis. The climate boundary condition is applied to the ground surface of a “surface region” mesh. It cannot be applied to any geometry item, only the surface of a special surface region. The reason for this is to enforce a more finely discretized mesh at the ground surface.

The initial temperature condition is established using the material activation at a temperature of zero. Recall that the goal of this analysis is to determine if permafrost conditions can be maintained for a typical climate year. Accordingly, the model is solved for a number of successive years until a repeatable temperature cycle is established. For illustrative purpose, the example file is only solved for a period of one year, although four years of data are presented below. An additional period of time could be modeled by adding another transient analysis to the file. The adaptive time stepping scheme was enabled and set to allow time steps to reduce to as little as 0.25 days if necessary to facilitate convergence.

4 Material properties

The material used in this example is assumed to be silty sand with thermal conductivity and unfrozen water content functions in Figure 3. The water content is assumed constant at 35% by volume. This is entered as 0.35 in the Key In materials dialogue box. Finally, the unfrozen and frozen volumetric heat capacity values are input as 3145 KJ/m3/C and 2413 KJ/m3/C respectively.

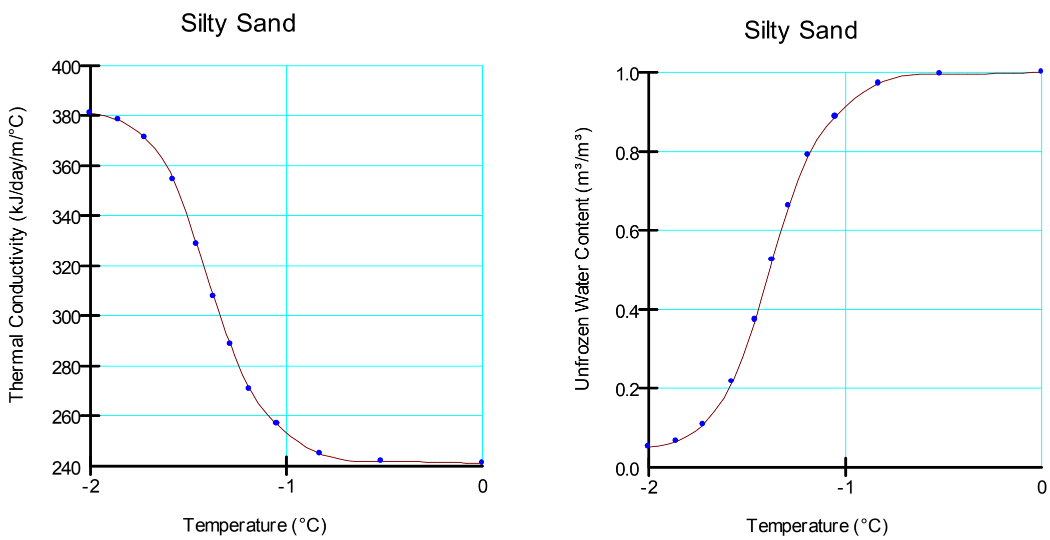


Figure 3 - Material properties

5 Results and Discussion

Figure 4 presents the temperature decay for the three elevations located at the line of symmetry beneath the thermosyphon. The results suggest that a repeatable temperature cycle is establishing at these locations after approximately two-years, which implies that the influence of the rather arbitrary starting condition is beginning to diminish. However, the downward trend of the peaks demonstrates that the analysis should be solved for additional time.

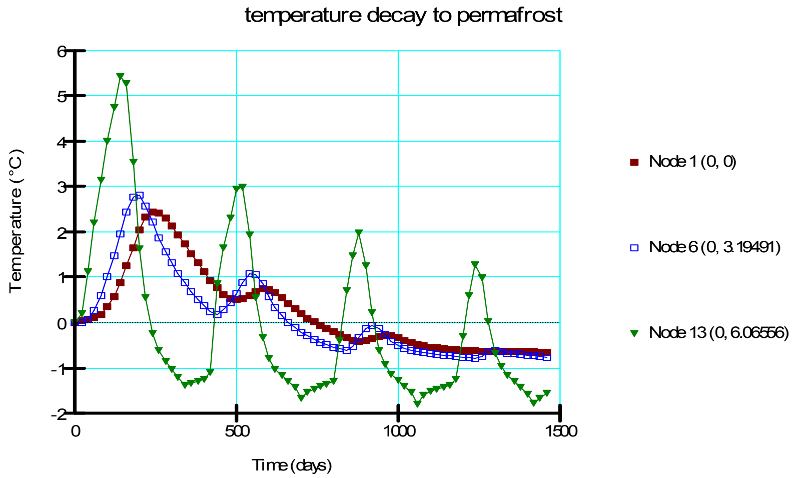


Figure 4 Temperature decay at the line of symmetry

Figure 5 presents a horizontal temperature profile at an elevation of 4 m in the middle of summer and end of the year for year four. The main objective of the analysis is to ensure that the thermosyphons remove the heat added by the building and that the permafrost does not suffer permanent damage below the building. The temperatures remain near or below freezing throughout the year, although the analysis should likely be solved for a longer time period.

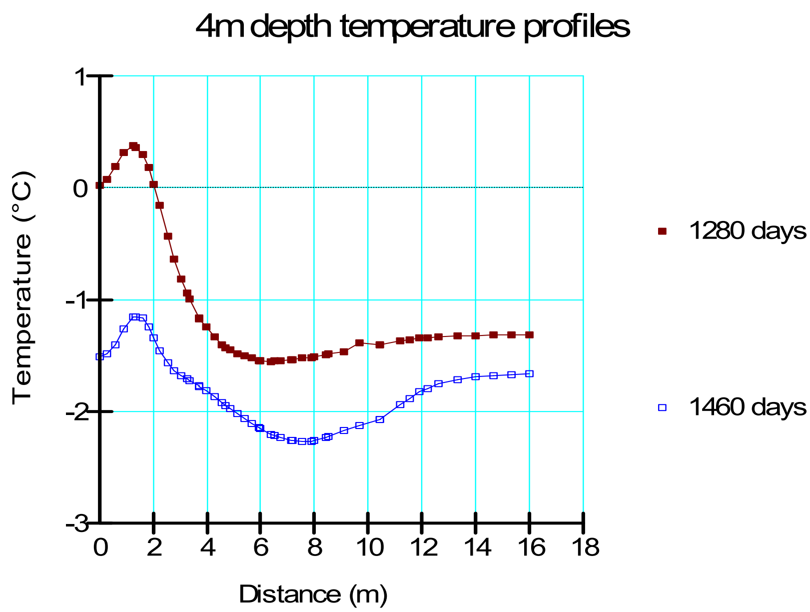
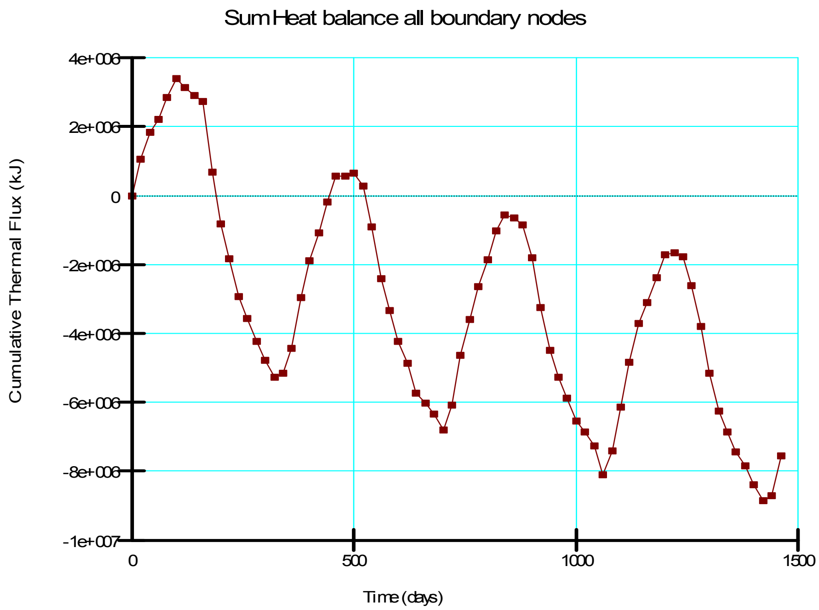


Figure 5 Horizontal temperature profile at elevation 4 m

Figure 5 presents the cumulative heat flow across all boundary conditions. Separate plots of the heat added via the foundation and deeper geothermal heat flow and heat removed via the climate boundary and thermosyphons are included in the file. It is apparent that that the heat loss from the thermosyphons and climate boundary exceed the foundation heat load, which is in-keeping with the decaying ground temperatures.



A movie file is included in the same folder as this document and is named "thermosyphons in end view.avi"   The contour range viewed for the movies was all temperatures above zero. Therefore, the areas without contours represent the permanently frozen zone.

6 Summary and Conclusions

This example demonstrates the use of thermosyphons to maintain the permafrost zone beneath a heated building. Thermosyphons are modeled in TEMP/W using a special boundary condition that normalizes the heat extraction rate for the length of pipe in the out-of-plane direction. It also accounts for the size of the radiator and operating temperature. The initial temperature of the domain is arbitrarily set to zero degrees and the analysis is solved for a number of years until a repeatable temperature cycle is established.