May 2019

Design Studio Specialization Project

Athens, Greece Regional Airport
Passive HVAC Energy Analysis

Justin Guinn
University of Texas
Cockrell School of Engineering

Contents

Intro

This paper investigates the effectiveness of a passive cooling system using underground piping systems to moderate air temperatures needed to chill or heat to reach thermal comfort. The thought is fresh air is pulled through the underground pipes with HVAC systems. Using soil as a thermal mass to transfer thermal energy between the air and pipes could reduce the temperature difference of supply air resulting in energy savings. The closer the supply air is to desired set point the less energy needed to reach thermal comfort.

Figure 1: Design studio regional airport project with passive cooling system

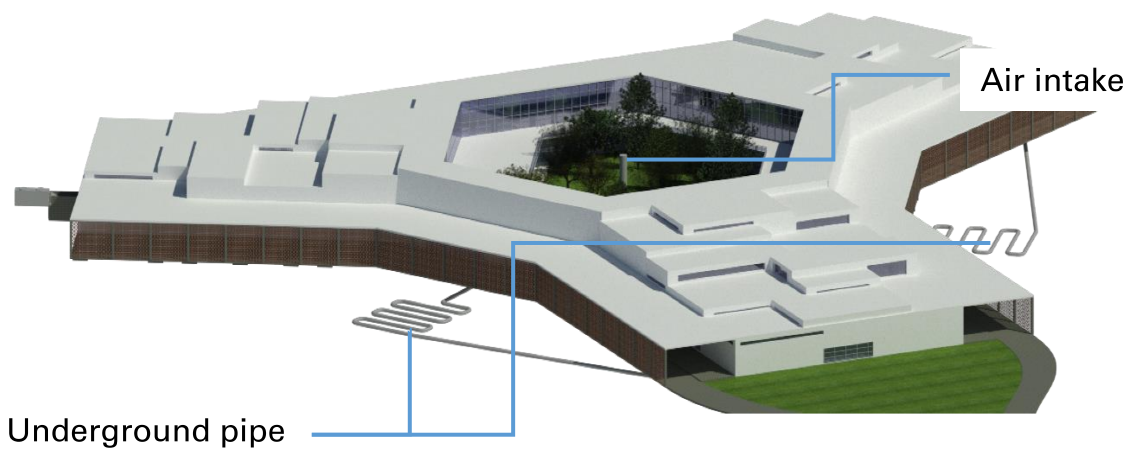


Figure 1 demonstrates what these pipe system design could be.

Assumptions

A key aspect of this project are the assumptions. The assumptions will allow up to develop equations for modeling.

- The ground is a constant temperature
- Density of the air is constant, 1.2 [kg/m^3]
- Energy difference of the air is equal to the energy difference of the pipes
- Pressure remains constant
- HVAC systems will run continuously

- Air is dry
- Convection coefficient is constant

Equations and Constants

Re – Reynolds number

$$Re = \frac{\rho * D * v}{\mu} \geq 4000$$

Reynolds number must be greater than or equal to 4000 to achieve a turbulent flow. Turbulent flow is needed to transfer energy efficiently.

h – Convection coefficient for turbulent flow inside tubes.

$$h = \frac{C_p * G^{0.8}}{D^{0.2}}$$

(ASHREA Handbook 2001 fundamentals chapter 3, page 14 equation 8)

Qsoil – Energy transfer between outdoor air and supply air.

$$Qair = v * \rho * C_p \; * \Delta T$$

Qconv – Energy from convection with in tubes of HVAC system

$$Qconv = \; A * h \left(\frac{(T_{oa} - T_{soil}) - (T_{su} - T_{soil})}{Ln\left(\frac{(T_{out} - T_{soil})}{T_{su} - T_{soil}}\right)} \right)$$

Equation based on assumption that energy transfer from air to pipes are equal

$$Qconv = Qair$$

Tsu [C] – Theoretical temperature of supply air reaching air handing units (AHU)

$$T_{su} = T_{out} - \frac{v * \rho * C_p}{A * h} \left(\frac{T_{oa} - T_{su}}{Ln\left(\frac{(T_{oa} - T_{soil})}{T_{su} - T_{soil}}\right)} \right)$$

Rearranging our energy transfer equations, we can solve for Tsu, because this equation is nonlinear the method to solve this equation will be MatLab. MatLab code can be found at the end of this document for reference.

Defined are a few constants or important numbers.

$G\ \left[\frac{kg}{m^2 s}\right]$	– Mass velocity	= 1.2
$C_p\ \left[\frac{kJ}{kg\ C}\right]$	– Specific heat	= 1.007
$\mu\ \left[\frac{N\ s}{m^2}\right]$	– Absolute of dynamic viscosity	= 18.25 x 10^{-6}
$\rho\ \left[\frac{kg}{m^3}\right]$	– density	= 1.2
$v\ \left[\frac{m}{s}\right]$	– Velocity	Variable

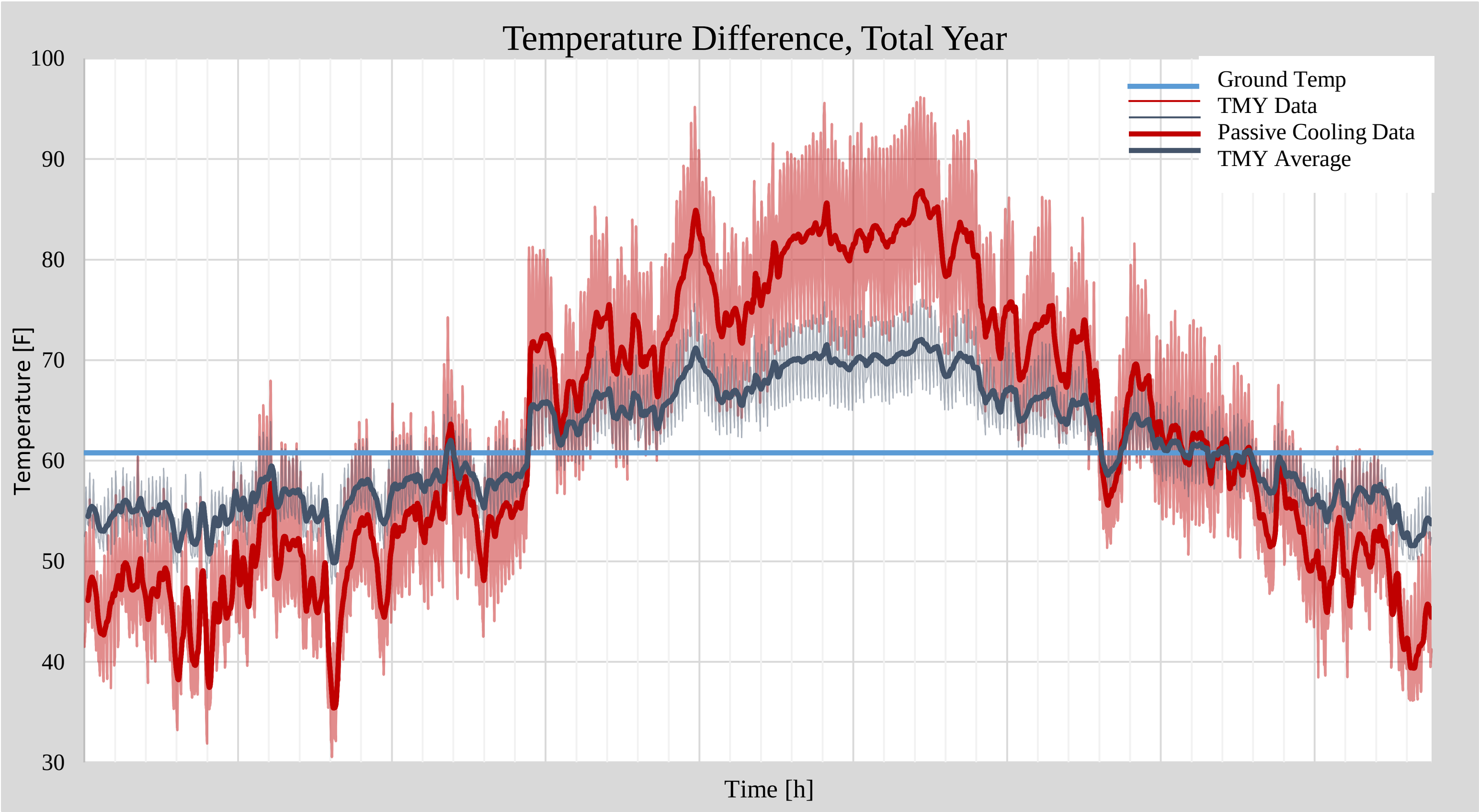
Data

We will now look into three cases, first looking at temperature and energy from a typically metrological year TMY. Second the change of temperature with change in velocity. And lastly the change of temperature with change of pipe surface area.

Note: All calculations were made using metric system

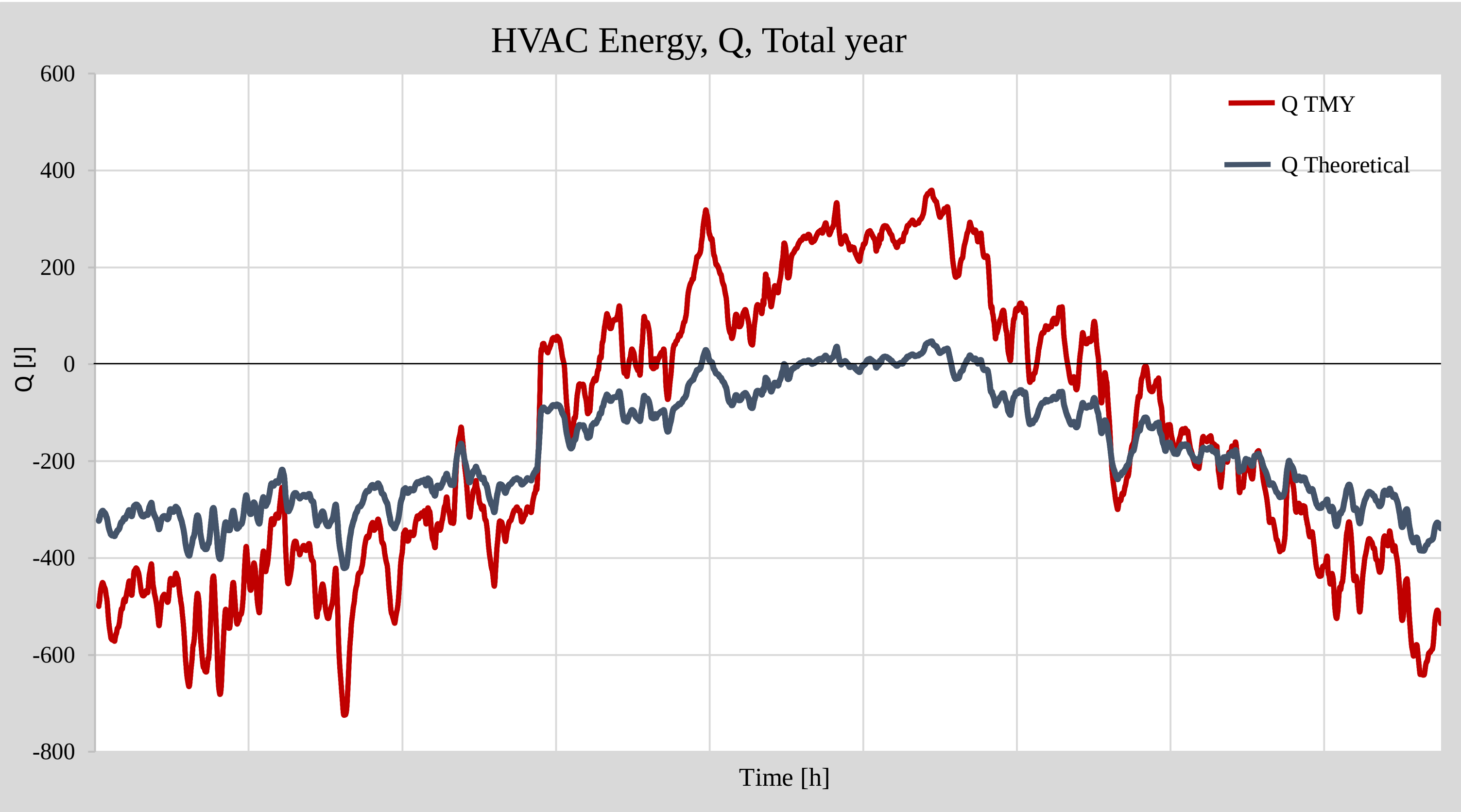
Typical Year

Figure 2: TMY and theoretical passive temperature data.



This graph is temperature for an entire year, time is in hours. In this graph the solid blue line represents the ground temperature, or the average air temperature. The red is outdoor temperature and the blue is the calculated theoretical temperatures. The darker bold lines represent the average of the temperatures.

Figure 3: HVAC energy calculations using TMY and theoretical temperature data



This is HVAC energy for the entire year. Below 0 is when the air is needed to be warmed and above is cooling. The HVAC energy was calculated with a set point of 72 °F. Meaning climate control will constantly chill or warm the spaces to 72 °F without shutting down. Red being the energy needed to condition normal outdoor air. Blue is the theoretical energy needed to condition to desired temps. This graph reveals the

Effects of Velocity

In this section the effects of velocity with a constant tube surface area of 339 ft^2 is calculated. Moreover, each graph below is a single day, winter and summer solstice instead of a total year.

Figure 4: Winter Solstice temperature variations with change of velocity

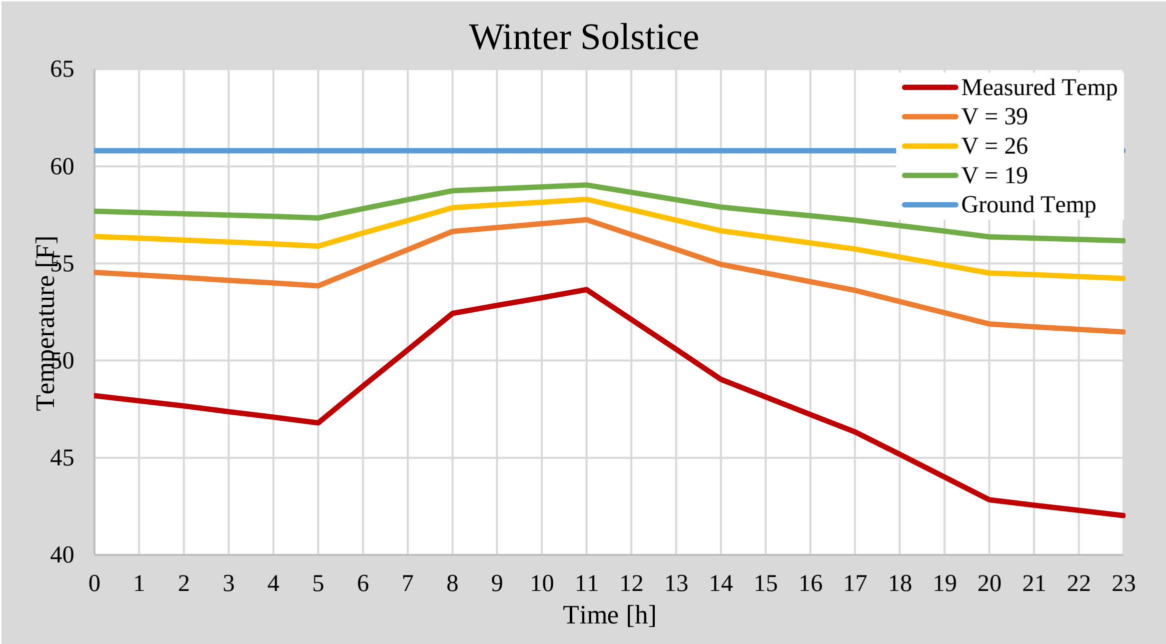
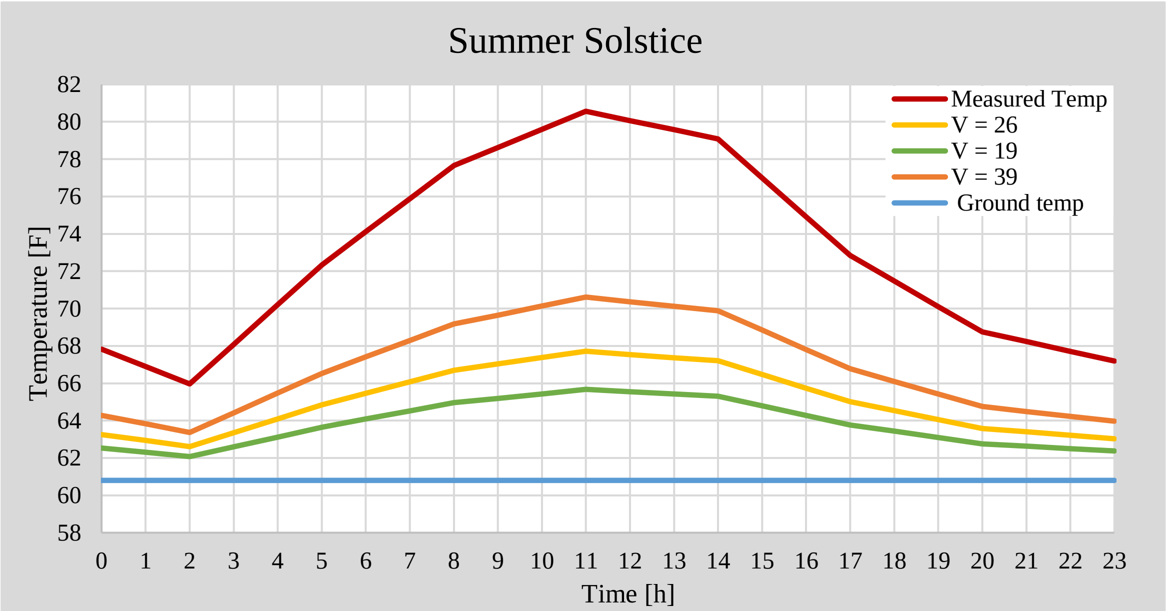


Figure 5: Summer Solstice temperature variations with change of velocity



These graphs the blue line is the assumed constant ground temperature and the red line is the actual data. This data shows a trend, as the velocity decreases the air temperature becomes close to the ground temperature.

Effects of Area

The effects of are investigated in this section. For these calculations velocity and diameter is constant, 32ft/s, 78" respectively. The length of the pipe system is the variable. The longer the pipes the greater the surface area. Just as before these graphs are a single day, winter and summer solstice.

Figure 5: Winter Solstice temperature variations with change of velocity

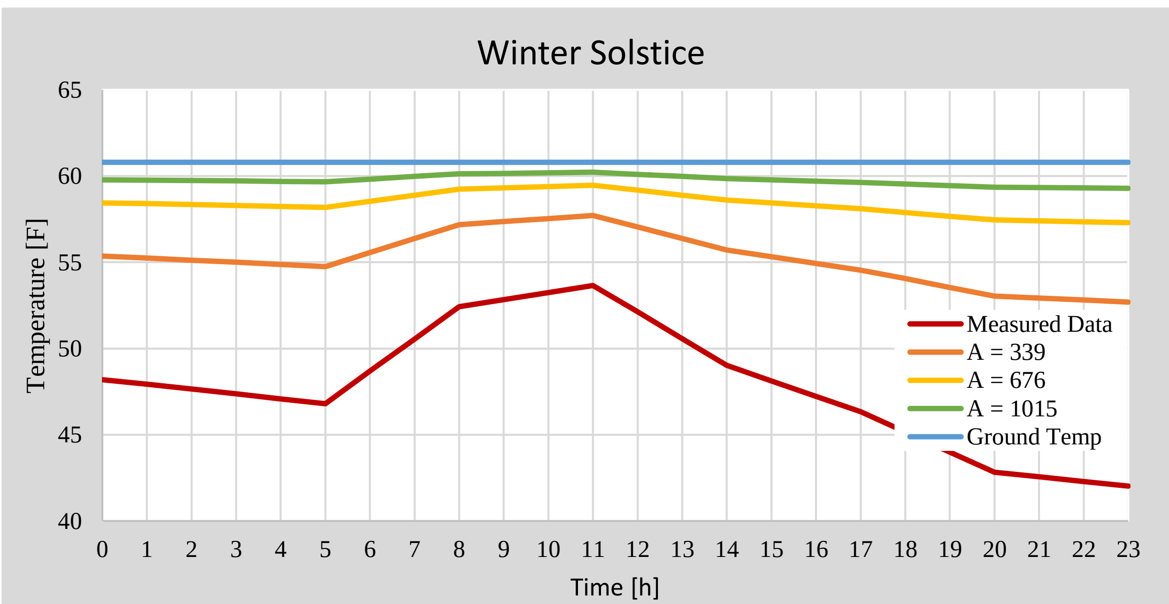
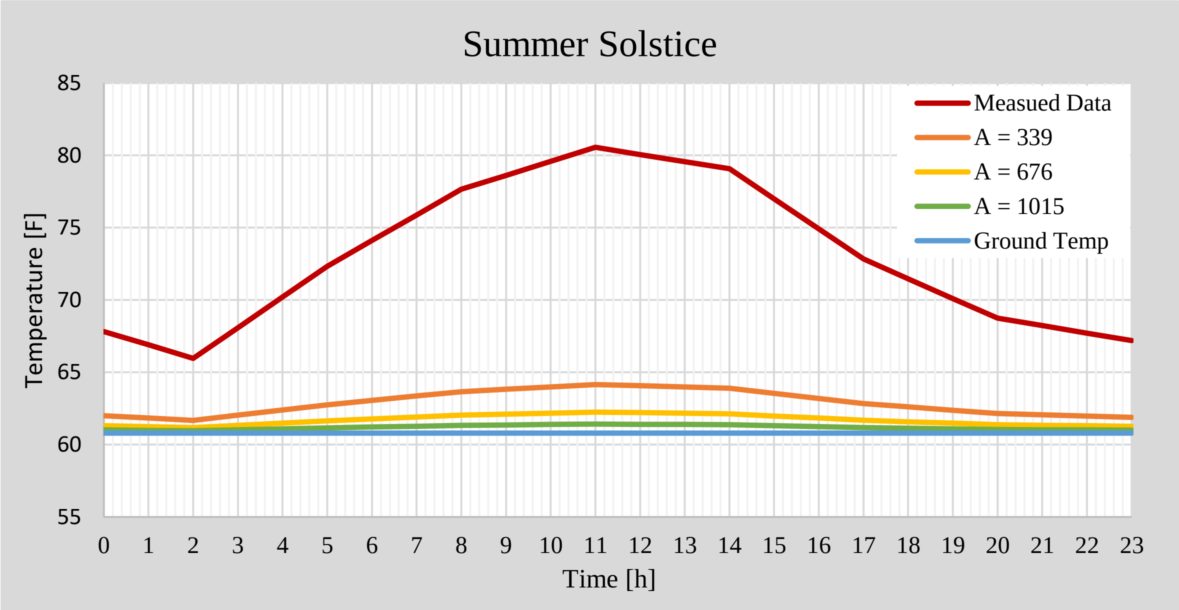


Figure 6: Summer Solstice temperature variations with change of area



We see the same effects are the velocity charts. However, area seems to have a great effect to changing air temps.

Conclusion

This model shows energy savings and temperature moderation could be possible with an underground passive cooling system. Additionally, the effects of surface area impact temperature moderations greater than velocity.

However, these calculations can be more accurate with additionally data such as pressure, relative humidity, and calculating depth at which soil is relatively constant year round.

References

ASHREA Handbook Fundamentals, 2001

This book contained many of the equations seen above.

European Commission
http://re.jrc.ec.europa.eu/pvgis5/tmy.html

Received TMY data for Anthens, Greece.

Code

```
% DESIGN STUDIO PASSIVE COOLING SYSTEM

%%
clc
clear

oldPrecision = digits;
digits(10);
%%

syms Tsup Qconv Qtrans
%%


%%
% Dimentions and Areas

Npipe = 1; %[#] Number of pipes
Lpipe = 5; %[m]
Lptot = Npipe *Lpipe; %[m]
dpipe = 2; %[m]
Cpipe = 3.14159 * dpipe; %[m]
circumference of pipe
Apipe = Cpipe * Lptot; %[m^2]


%%
% Assumptions Air & Properties
densityAir = 1.2; %[kg/m3]
CpAir = 1.007; %[J/kg*k]
Amass = 3.14/4*dpipe^2;
vel = 10; %[m/s]
Vol = vel * Amass; %[m^3/s]
MassRate = Vol * densityAir; %[kg/s]
G = 1.2; %[kg/m2s]

% Convection coefficient
h_air = CpAir*G^0.8/dpipe^0.2;

Constant =
(Apipe*h_air)/(MassRate*CpAir);

% Temperature of the soil
Tsoil = 16; % [K]

%%
% Import information from Excel

filename= 'Greececlimate.xlsx';

Tout = xlsread(filename,1,'B18:B8777');

%%
answer = zeros(8760,1);

for i = 1:8760
%%
% Energy Balance Equations

%conduction energy
%Qconv = Mass*CpAir*(Tout(i)-Tsup);

% Transfer energy

%Qtrans = Atube*h_air*(Tout(i)-
Tsup)/(log((Tout(i)-Tsoil)/(Tsup-
Tsoil)));


TempLog = log(((Tout(i)-Tsoil)/(Tsup-
Tsoil)));

Total = Tsup - Tout(i) +
(Constant)*((Tout(i)-Tsup)/(TempLog));

%%
%Total = -Qconv + Qtrans;

%%
TsupS = solve(Total == 0, Tsup);
%

answer(i,1) = TsupS;

Newfile = 'Tempdata.xls';
xlswrite('Answers', answer, 1,
'B2:B8761');
end

answer;
%%
```