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ASSESSMENT OF GROUND TO AIR HEAT TRANSFER SYSTEM FOR LOCAL SOIL CONDITIONS

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Abstract- Northern Pakistan has an extremely cold climate that requires a heating system during the winter season. On the contrary, extreme heat with high humidity and electric power cutoff cause inhabitant discomfort in summer. In this paper, an assessment of shallow geothermal feasibility is proposed to provide heating during winter and cooling during summer. The capital is considered the study area; nevertheless, it can be extended to other regions of the country, such as Northern areas that are extremely cold during winter and southern areas that are very hot during the summer. Furthermore, for the location under consideration, it is found that the soil strata in different regions are not the same. Therefore, the current paper also focuses on assessing shallow geothermal energy for different soil types in the selected region. Isotherms and precipitation contours have been developed that are based on 36 years of data. Islamabad receives the highest precipitation throughout the year; therefore, wet, and dry soil conditions are considered. The numerical model is validated with the analytical expression with the soil of Madinah Saudi Arabia. The result showed that different soil conditions affect the ground temperature for the same region having a similar climatic condition.

Keywords- Geothermal, Renewable energy, Climatic condition, Ground temperature.

1. Introduction

Pakistan imports fossil fuel in the form of petroleum and hardly accomplishes the domestic energy demand. Geographically it lies between (24^0–37^0) North latitudes and (62^0–75^0) East longitudes and has a wide range of thermal variation from place to place. Mountains dominate the north areas with humid to arid climatic conditions; higher altitudes receive winter precipitation as snow. The middle Indus River basin is tropical and continental, whereas an arid climate characterizes the lower Indus River basin. Baluchistan is characterized by an arid climate that receives the lowest rainfall and is prone to desertification [1] [2]. It has been found that while the considerable potential for geothermal energy is available, no appreciable practical steps have been undertaken in this regard. Zaigham et al. [5] show that the hydro-geothermal option is one of the most viable renewable sources considering Pakistan's tectonic system. Soil temperature varies from month to month due to incident solar radiation, rainfall, seasonal cycle in overlying air temperature, local vegetation, soil type, and depth. Aftab et al. [3] studied the exploration prospects of geothermal energy in Pakistan. Kazmi and Sheikh [4] studied a Hybrid geothermal–PV–wind system for a village in Pakistan. They found that enough geothermal energy is available from hot springs to cater to the perennial base load requirement of the small community. Zeb et al. measured the thermal transport properties of porous igneous basalt rocks using the Transient Plane Source (TPS) technique under ambient air conditions saturant in pore spaces[5].

Luckily, Pakistan receives plenty of sunshine; therefore, shallow geothermal energy resources are available in all the regions from various depths and can be used for cooling & heating of buildings and supply of hot water during the winter season [6].

2. Selected region

This study investigates the effects of both dry and wet soil; therefore, the capital Islamabad has been considered as the study case. The city has variation in soil profiles and receives higher precipitation than other parts of the country. The climatic data used in the paper is based on 36 years mean values obtained from RET screen [7]. The earth temperature for different years is considered, and the cosine function is used to derive the amplitude for the Islamabad climate (See **Figure 1**). Whilst **Figure 2** shows the isotherms of earth temperature for the whole Pakistan.

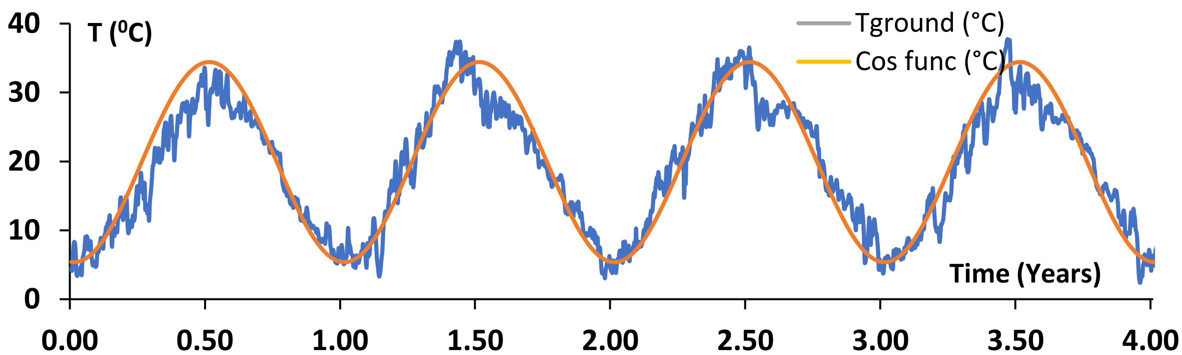


Figure 1: Earth temperature for Islamabad city based on RET screen database [7]

The station used for the climatic data is located at Latitude equal 33.7^0 N and Longitude 73.1^0 E. The 36 years Air temperature - average (°C) is 20.6, Air temperature - minimum (°C) is -0.06, Air temperature - maximum (°C) is 42.6, Earth temperature (°C) is 19.9 (°C) with Amplitude 14.6 and Phase shift 0.1.

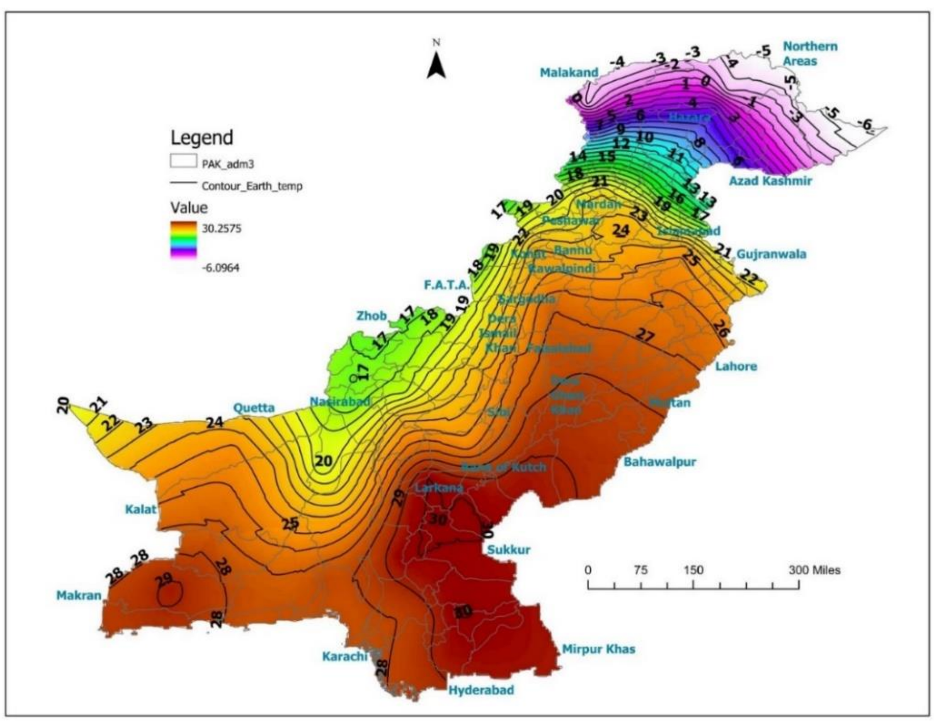


Figure 2: Mean annual Isotherms of Earth temperature based on 36 years of data.

Six cases of different soil characteristics have been considered in this study; the details of the study cases are shown in Table 1.

Table 1: Considered soil types.

Type of soil	Cases	Description of soil
Type 1-Fine (CL/ML)	Case 1	Soft cohesive soil
	Case 2	Stiff Cohesive soil
	Case 3	Hard Cohesive Soil
Type-2 Granular (SP/SW)	Case 4	loose sandy soil
	Case 5	Medium sandy soil
	Case 6	Dense Sandy Soil

In this study, the top soft/loose superficial soil has been ignored. Soil profiles consistent with the workable depth of 3m - 15m have been adopted [8]. The most intercepted soil types of the region and their respective thermal and geotechnical properties are considered. The thermal conductivity values are calculated as per [9]. They are based on respective soil types and degree of saturation. In contrast, the volumetric heat capacity has been selected based on [10] [11].

3. Soil Temperature and Numerical simulations

The heat balance scenario on the ground surface due to fluxes (conductive, convective, and thermal radiation) is shown in **Figure 3**. It is beneficial to estimate the maximum soil temperature at a certain lying depth. The air temperature is assumed to fluctuate sinusoidally throughout the year. The soil damped the temperature depending on its thermal diffusivity.

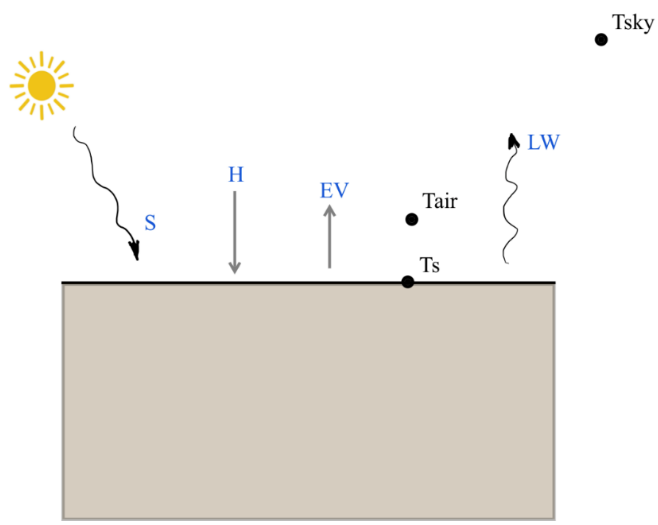


Figure 3: Heat fluxes on the ground surface

The cosine function given by Eq. (1) is used to model fluctuations in temperature data throughout the year.

$$T_s(t) = T_{sm} - A_s \cos(\omega t - \phi_s) \qquad \textbf{(1)}$$

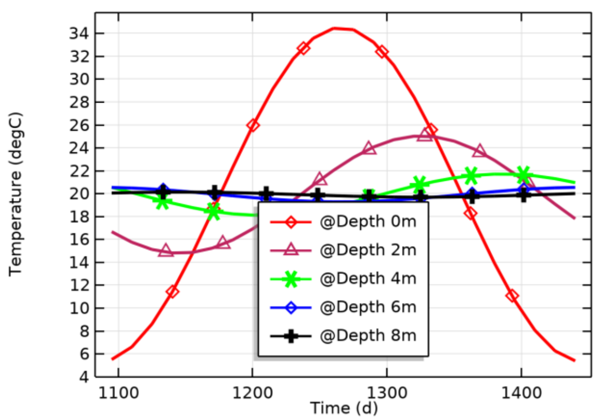
The soil temperature is the ambient soil temperature at a particular depth. It is based on a mathematical model describing the soil's standard temperature curve shown by Eq (2) [12]. Analytically, ground temperature varies with location and time and is based on the assumption that the ground's surface temperature varies periodically. The soil is a homogeneous heat-conducting semi-infinite medium with constant thermal diffusivity. The average ground temperature "T" is a function of depth z and time t and has the analytical expression given by Eq (2) [12].

$$T(z,t) = T_{sm} - A_s \exp\left(-\frac{z}{L}\right)\cos\left(\omega t - \phi_s - \frac{z}{L}\right) \qquad \textbf{(2)}$$

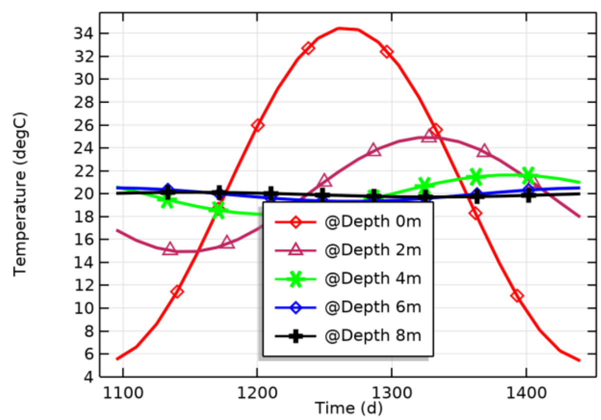
COMSOL Multiphysics numerical code [13] has been implemented to model the soil profile that was initially validated using climatic data of Islamabad and soil conditions for Madinah Saudi Arabia. The details of soil and climatic and conditions for Al-Madinah area can be found at [14]. The required parameters for Madinah climate that has been used in the model validation were: T_{sm} = 29.6 ºC, L = 2.8345 m, $\alpha = 8.12 \times 10^{-7}$ m²/s, A_s = 11.16 ^{0}C, ϕ_s = 0.39. The validation is based on the values obtained from COMSOL for the 4th year due to transient. The numerical model is validated using the analytical Eq (2).

4. Results and discussions

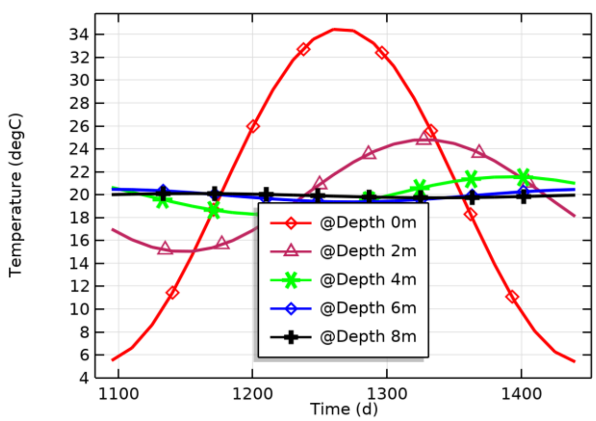
Depend on the groundwater measurement point's location, considerable differences can be seen in the temperatures at increasing depth. A deeper ground loop installation usually decreases the annual operating cost to run the heat pumps. During a GHP system's service life, these accumulated savings may compensate for the higher initial cost of burying the ground loop at a higher depth. To determine the optimal depth, it is essential to investigate the seasonal change in soil temperature with depth using the soil's thermal properties. The variations of temperature throughout the 4th year at 2 m, 4 m, 6 m, and 8 m depths have been shown (See **Figure 4**) for 6 considered cases. These depths show the fluctuation of the temperature during the year. From there, it can be observed that the temperature of the ground becomes constant at about 8 m depth. Furthermore, it can be seen that installing the geothermal system at a depth of 2 m onward is feasible as the temperature difference is reasonable for heating and cooling systems.



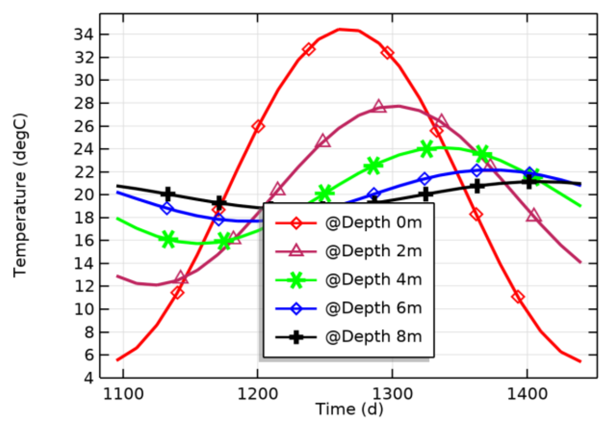
a) Case 1 Soft cohesive Soil



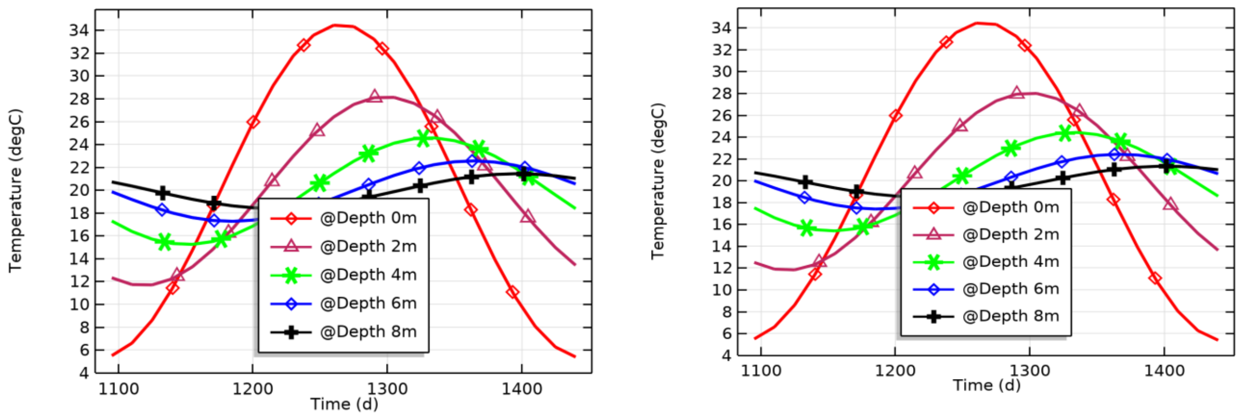
b) Case 2 Stiff Cohesive soil



c) Case 3 Hard Cohesive Soil



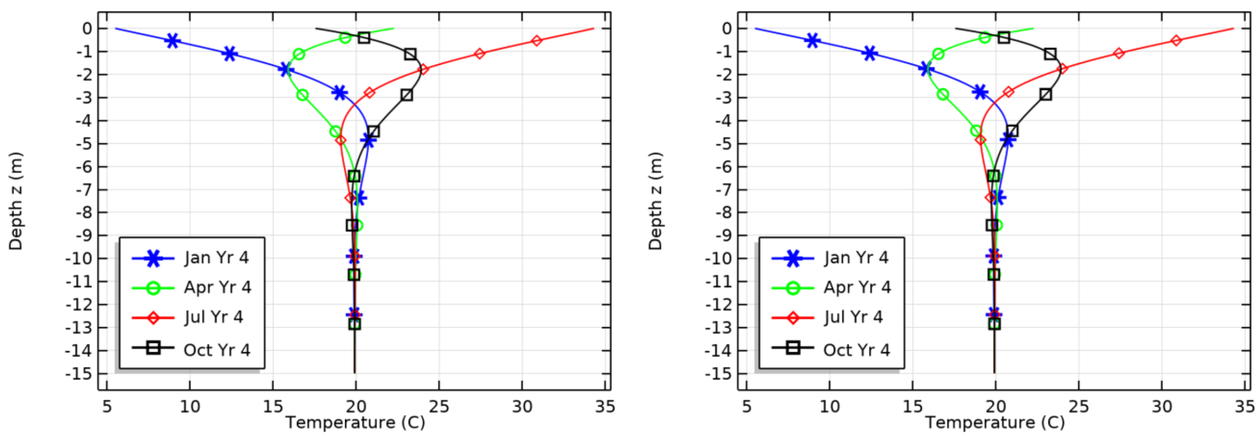
d) Case 4 loose sandy soil



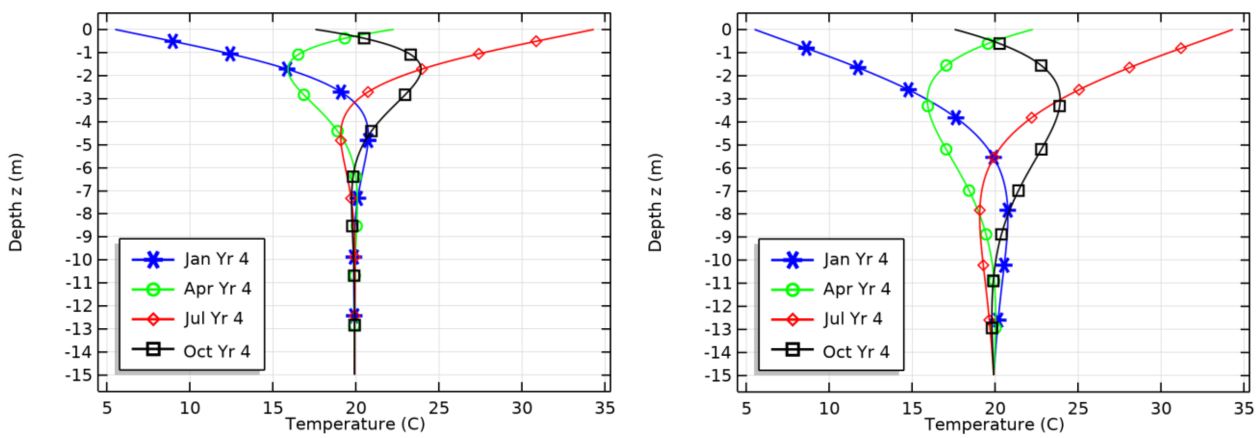
e) Case 5 Medium sandy soil *f) Case 6 Dense Sandy Soil*

Figure 4: Daily temperature variations against Different Depth for Cohesive soils (a-c) and Granular Soils (d-f).

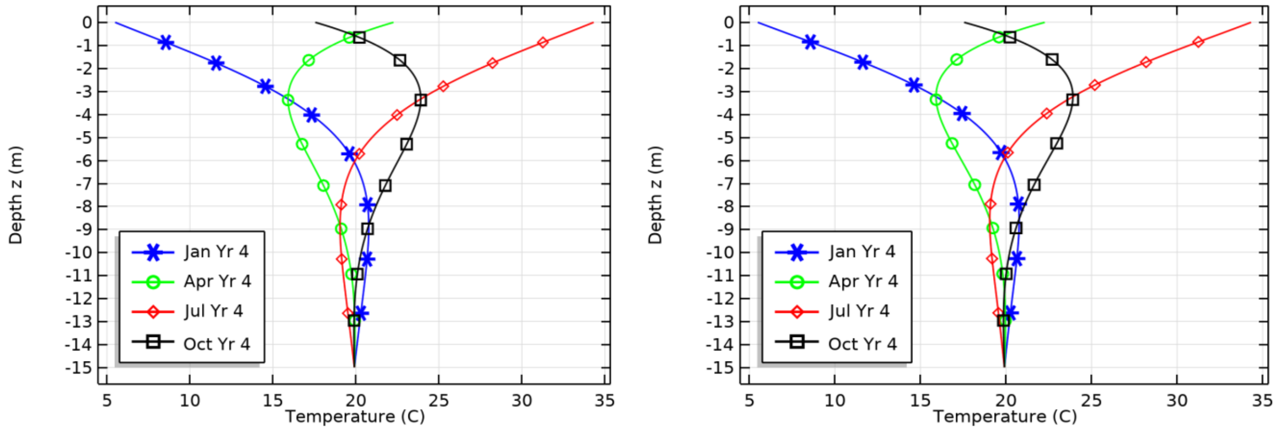
The variation of temperature and depth has been shown in **Figure 5** for the studied fine and granular soil cases.



a) Case 1 Soft cohesive Soil *b) Case 2 Stiff Cohesive soil*



c) Case 3 Hard Cohesive Soil *d) Case 4 loose Sandy Soil*



e) Case 5 Medium Sandy Soil *f) Case 6 Dense Sandy Soil*

Figure 5: Subsurface Seasonal Temperature gradient for Islamabad region Cohesive soils (a-c) and Granular Soils (d-f)

The above results reflect more heat-trapping and low conductivity of cohesive soils as compared to the sandy soils. The primary reason for such difference is the smaller grain and respective pore size. The air, a natural insulator present in the pores, is extensively distributed along the smallest thread like clay particles and a heat transfer barrier. In coarse grain soil, the granular particles have larger interparticle voids and larger grain to grain contact, which permits conduction. The mineralogical comparison of both soil types can be helpful for further elaborating heat transfer in regional soils.

5. Conclusions

The paper has dealt initially with the climatic data and subsurface thermal conditions. Different local soils of Islamabad are assessed for the potential usage of shallow geothermal applications. Some interesting conclusions can be drawn. It has been observed that the cohesive soils of the studied region are less conductive and have low thermal disparity concerning the seasonal variations. At the same time, sandy soils are easily affected by climatic conditions. In cohesive soils, the stable subsurface temperature gradient is intercepted at a depth of 7 m.

Nevertheless, in granular soils, effects of seasonal and climatic variations reached up to 15 m depth. The Installation of geothermal HVAC systems can be more efficient and cost-effective in clayey and fine soils than the granular soils. The comprehensive experimental and field investigations of heat transfer mechanism in local soils under various geotechnical conditions such as soil type, porosity, density, and mineral composition are potential future research topics. These can be used in the feasibility design of geothermal systems.

6. Appendix

$T(z,t)$	=	Temperature	[K]
T_{sm}	=	Annual average temperature at the ground surface	°C
A_s	=	Maximum annual temperature variation from average	°C
a	=	Thermal diffusivity of soil	m^2/sec
ω	=	Angular frequency of temperature fluctuations	1/day
α	=	Thermal diffusivity	[m^2/s]
K	=	Thermal conductivity	[W/(m.K)]
ϕ_s	=	Phase angle	[rad]
S	=	Solar radiation	
H	=	Convective heat flux	
Ev	=	Evaporative heat flux	
GHP	=	Geothermal Heat Pump	
GSHP	=	Ground Source Heat Pump	
ρ	=	Density	g/cm^3
k	=	Thermal Conductivity	(W m−1 K−1)
Cv	=	Heat Capacity	MJ/m^3

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