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COLLECTION AND ANALYSIS OF SOIL THERMAL PROPERTY DATA UNDER MINNESOTA'S LOCAL CONDITIONS

ABSTRACT

The aim of this research was to collect and collate soil thermal property data across Minnesota to support the ongoing modelling of Ground Source Heat Pump systems (GSHPs). The soil properties of interest essential in the numerical modelling of GSHPs are thermal conductivity, density, specific heat capacity, soil layers by depth and water content.With the knowledge of these properties, the precise performance of a GSHP at a given location can be numerically established. Soil thermal property data was obtained by reaching out to Northern Groundsource Inc which is a geothermal systems company in Minnesota. Data was also obtained from the Minnesota State Climatology Office, University of Minnesota Extension, Minnesota Emergency Communications Board and Minnesota Pollution Control Agency by searching their databases and websites. The predominant soils in Southwest and South-central Minnesota which are loamy soils exhibited the highest thermal conductivity of 1.263 $Wm^{-1}K^{-1}$ at wilting point and 1.730 $Wm^{-1}K^{-1}$ at field capacity and the specific heat capacity ranges from 1140 to 2090 $Jkg^{-1}K^{-1}$ at moisture contents of 0.01 to 0.20 kg/kg and soil density of 1200 kgm^{-3}. The properties were measured up to a depth of 1.83 meters and would be suitable for the design of horizontal GSHPs which are usually installed between 1.524 m and 3.048 m.

BACKGROUND

GSHPs provide space heating and cooling with significantly higher efficiencies by utilizing deep ground stable temperatures ("Geothermal Heating"). The GSHPs are installed either horizontally over a surface at least thrice the surface area of the building's floor plan (between 1.524 m and 3.048 m beneath the surface) or vertically (100 meters or more) as a borehole (Said et al., 2009); "Geothermal Heating"). The thermal properties of the backfill materials used and of the soil where GSHPs installation sites are located are among the most important factors for design and sizing of GSHPs. Even with the several investigations on the performance of GSHPs, the thermal properties of the soil vary from location to location and have to be determined in order to properly size GSHPs. This research aims to fill that gap by collecting and analyzing soil thermal properties for potential sites in Minnesota.

METHODOLOGY

The methods applied in this research were data collection and data analysis. A map of the different regions that also shows which counties are in each region of Minnesota was obtained from the Minnesota Emergency Communications Board. Data about the predominant soils in specific regions was obtained from the Minnesota State Climatology Office and University of Minnesota Extension. Thermal conductivity, thermal diffusivity, bulk density and water content data was obtained by reaching out to Northern Groundsource Inc which is a company specializing in geothermal heating and cooling systems. Soil secondary physical properties and processes were obtained from the Minnesota Pollution Control Agency.

RESULTS

Thermal characteristics impact the temperature and heat flow in soils with respect to time and depth because they influence the retention and transmission of heat in soils. Minnesota has the following predominant soils in different zones; Northwest Minnesota had predominantly clay soils, Northeast Minnesota had predominantly peat soils, Central and Metro Minnesota had predominantly sandy soils, Southeast Minnesota had predominantly silty soils and Southwest/South-central had predominantly loamy soils (James et al., 2021); (“Minnesota State Climatology [ ]”). The map below shows the different regions of Minnesota that were used in determining the predominant soils.

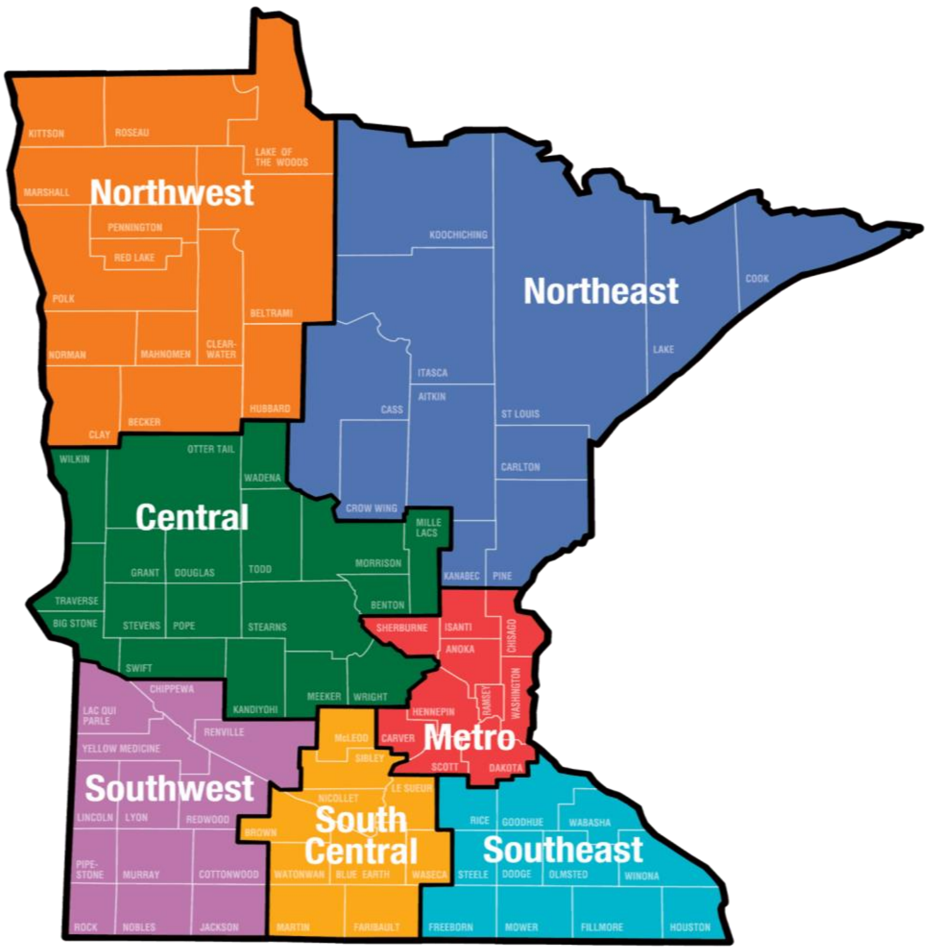

Figure 1: Political map of regions of Minnesota with counties in each region indicated (*www.mnecb.org* ,and www.mnecb.org/287/)

Table 1 shows the different predominant soils in the regions of Minnesota and their thermal properties at a depth of 1.8288 meters and above. (“Northern Groundsource Inc. [ ]”; James et al. [ ]; “Minnesota State Climatology [ ]”*)*

Area	Predominant soil	% of predominant soil in samples used	Bulk density (g/cm^3)	Water content wilting point (kg/kg)	Water content at field capacity (kg/kg)	Thermal conductivity in $Wm^{-1}K^{-1}$ at wilting point	Thermal conductivity in $Wm^{-1}K^{-1}$ at field capacity	Thermal diffusivity in (m^2/sec) at wilting point	Thermal diffusivity in (m^2/sec) at field capacity
Northwest	Clay	72.9% clay	1.0-1.2	30.1	37.2	0.88208	1.07234	$3.54838e^{-7}$	$3.87096e^{-7}$
Northeast	Peat	38.3% clay	0.2-0.3	16.5	28.6	1.02045	1.3664	$4.40859e^{-7}$	$4.94623e^{-7}$
Central/ Metro	Sand	87.6% sand	1.1-1.3	3.3	11.5	0.84749	1.85065	$5.3763e^{-7}$	$8.6021e^{-7}$
Southeast	Silty	65.6% silt	1.3-1.4	9.1	21.7	0.8302	1.43555	$4.62365e^{-7}$	$5.59139e^{-7}$
Southwest/ Southcentral	Loamy	35.5% sand, 36.4 silt, 28.1% clay	1.2-1.5	11.5	20.2	1.26259	1.72958	$6.23655e^{-7}$	$6.66665e^{-7}$

Definition of terms used in the table

Bulk density is a standard measure of soil density, defined as the proportion of a soil's weight to its volume. It is defined as a weight per volume unit. Water content is the ratio of the weight of water to the weight of the solids in a given mass of soil. Thermal conductivity at the wilting point is the lowest predicted value in the field. Except in saturated conditions, field capacity thermal conductivity is the highest predicted value in the field. Thermal diffusivity at the wilting point is the lowest expected value in the field. Except in saturated conditions, field capacity thermal diffusivity is the highest expected value in the field (Datta et al., 2018).

Specific heat capacity increased with increase in moisture content and soil density and consequently soils had higher thermal conductivity. In a study conducted by Nusier et al., () on the effect of water content and bulk density on specific heat and volumetric heat capacity of sand and loam Soils, specific heat capacity ranges from 1140 to 2090 $Jkg^{-1}K^{-1}$ for loam soils and 800 to 1530 $Jkg^{-1}K^{-1}$ for sand at moisture contents of 0.01 to 0.20 kg/kg and soil density of 1200 kgm^{-3}(Osama and Abu-Hamdeh, 2020).

Secondary physical and chemical properties were also analyzed, and the following observations made: ("Soil Physical Properties")

Sand: When compared to soils with significant clay concentration, sand has restricted structural development, rapid infiltration, rapid drainage, poor water holding capacity, mineral and organic material leaching, and chemical and biological processes.

Silt: Silt has a weak structural development, low infiltration rates, is well drained, has low chemical and biological processing rates, and is quickly eroded and compacted.

Clay has sluggish penetration rates, is poorly drained, has a high-water holding capacity, has high chemical processing rates when not compacted or saturated, and is quickly compacted.

Loam: Because loam is made up of sand, silt, and clay, it is well drained, has a high-water holding capacity, and is chemically and biologically varied and active.

CONCLUSION

Using the secondary data collected from different sources, the research revealed that Southwest and South-central Minnesota's soils exhibited the most suitable characteristics for installation of horizontal GSHPs. The predominant soils in these regions were loamy soils which exhibited the highest thermal conductivity of 1.263 $Wm^{-1}K^{-1}$ at wilting point and 1.730 $Wm^{-1}K^{-1}$ at field capacity and the specific heat capacity ranges from 1140 $Jkg^{-1}K^{-1}$ to 2090 $Jkg^{-1}K^{-1}$. The thermal properties found in this research may be used in installation of horizontal GSHPs which are usually installed 1.524 m and 3.048 m underground. With Minnesota having an average frost depth of 0.673 m ("Frost depth"), the results would be suitable for use when installing below that depth. This research can be improved on by finding soil thermal properties of soils in Minnesota's specific counties as compared to the different zones used in this research. It can also be improved upon by finding variations in soil thermal properties by depth.

REFLECTIVE STATEMENT

The research helped me sharpen my organization, time management, research, and collaborative skills. With more time, I would have found soil thermal properties county by county in Minnesota and the variations of the soil thermal properties with depth. Nonetheless, it was an eye-opening experience that guided me towards my goal in sustainability and clean energy systems.

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