Community-Scale Geothermal Network in Chicago

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ABSTRACT

This paper focuses on the preliminary investigation for a community-scale geothermal system in the West Woodlawn neighborhood of Chicago, Illinois, United States. Growing challenges posed by climate change and increasing urbanization, and the need for a secure and resilient energy grid; community-scale geothermal systems offer an innovative solution to decarbonize building heating and cooling systems. These systems can significantly lower energy costs and reduce dependence on fossil fuel-based power grids. This project will contribute to Blacks in Green (BIG)™ effort to develop a "Sustainable Square Mile", which aims to design and develop green, self-sustaining, mixed-income, walkable villages in black neighborhoods. For this community-scale project we are designing a geothermal system based on a modular approach. This foundational study is being conducted with the collaboration from community members where the analyses are based on individual building's heating and cooling usage. The simulations also included new and existing, detailed subsurface information collected in the field and laboratory. This data was used to estimate underground thermal transport processes that were inputs in a preliminary system design following ASHRAE's design procedure for a borehole field. Our modeling results indicate that a representative module requires a total of 68 boreholes, each 150 meters deep.

Keywords: geothermal energy, community-scale network, decarbonization, green infrastructure, sustainable energy

1. INTRODUCTION

Fossil fuels for commercial and residential buildings contributes to approximately 30% of the total greenhouse gas (GHG) emissions in the United States (USEPA, 2024). Decarbonizing the country's buildings is a necessity for meeting; 1) future carbon emission goals; 2) improve air quality; 3) offer equitable access to lower energy costs; and 4) transition to clean, renewable energy sources. Shallow geothermal system networks offer a clean energy solution that can harvest geothermal energy and meet the thermal demands of buildings (Baser and McCartney, 2015). A single residential or commercial building geothermal system can reduce energy consumption and GHG emissions; however, despite numerous efforts the upfront costs are still high (Neves et al., 2020; Farzanehkhameneh et al., 2020). Community-scale geothermal systems can address these challenges and lead to faster transition to clean energy. Meng et al. (2019) presented a case study using a numerical model to assess the thermal impact and long-term sustainability of a neighborhood-scale geothermal system. The results showed limited thermal anomalies over time and confirmed the economic and environmental viability of the project. Meng et al. (2019) suggested a site-specific analysis to evaluate the long-term sustainability of the project. Zeh et al. (2021) proposed that using large-scale geothermal systems shift heating and cooling loads seasonally, leading to flexibility in the heating network. Garcia-Gil et al. (2020) suggested that the transition from fossil fuel-based heating and cooling systems cannot be achieved by technological improvement alone; instead, it requires the implementation of scientifically informed policies to effectively exploit the underground resources.

Therefore, they presented an adaptive management framework structure and a governance model and provided a roadmap for policymakers.

The technical advancements in geothermal systems and policy revisions on transitioning to 100% renewable energy usage motivates an increasing number of community-scale geothermal system installations. There are still opportunities for researchers to investigate the overall performance of these systems for efficient design practices. This study focuses on the design of a community-scale geothermal system in Chicago, IL. In this project, data pertaining to the subsurface properties and thermal demands from the existing buildings were collected from an extensive foundational study. An innovative design approach is proposed based on the existing data and ongoing efforts are presented.

2. PROJECT DESCRIPTION

2.1 West Woodlawn Neighborhood, Chicago, IL

The project aims to deploy a shared community geothermal network in West Woodlawn, a neighborhood on the South Side of Chicago. The overall goal of this project is to support the community to tap into a local energy that can help foster energy and environmental equality. Furthermore, this project supports Blacks in Green (BIG)'s effort to develop the "Sustainable Square Mile" https://www.blacksingreen.org/our-approach, launched in 2010, that is building a local green economy to satisfy the neighborhood needs. The vision of the initiative aims to improve the health and wealth of the community, mitigate the climate impacts, and establish scalable developments for other front-line communities.

The shared geothermal network will be deployed in Chicago's alley ways and public right of way and uses a modular approach allowing the residents and businesses to opt-in over time. The thermal loops will be designed with the flexibility for buildings to be added continuously

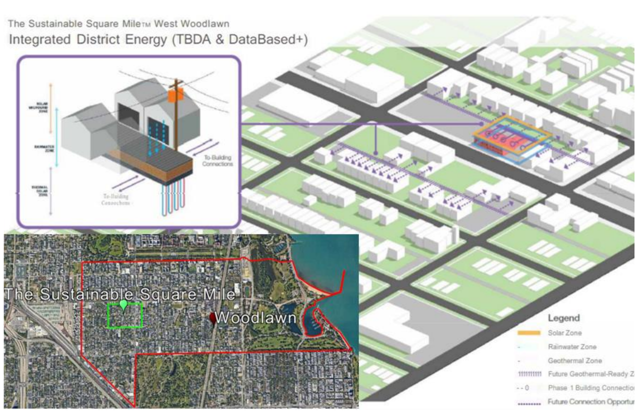

Fig. 1 *The proposed community geothermal system*

(Figure 1). At each building, a geothermal heat pump will be connected to the existing heating, ventilation, and air conditioning system, which could include natural gas furnaces, hydronic heating systems with radiators, or room air conditioners.

2.2 Site Footprint

The neighborhood area includes approximately 75 single-family, two-flat, or three-flat residences, 20 multi-family buildings having more than three units, 12 mixed-use or commercial buildings, and open lots where an additional 100 new residential units (single-family or multifamily) could be built along with five sites permitted commercial development. 100 new units of residential (single-family or multifamily) plus five sites for additional commercial development.

The proposed route for the geothermal loop and vault locations are shown in Figure 2(a). The underground pipe network would be constructed along five alleys. Once finished, the system will cover 12 city blocks which are all connected to a master pipe system serving the distributed wells and heat pumps. The geothermal system is divided into 12 modules as shown in Figure 2(b). A foundational study was conducted to

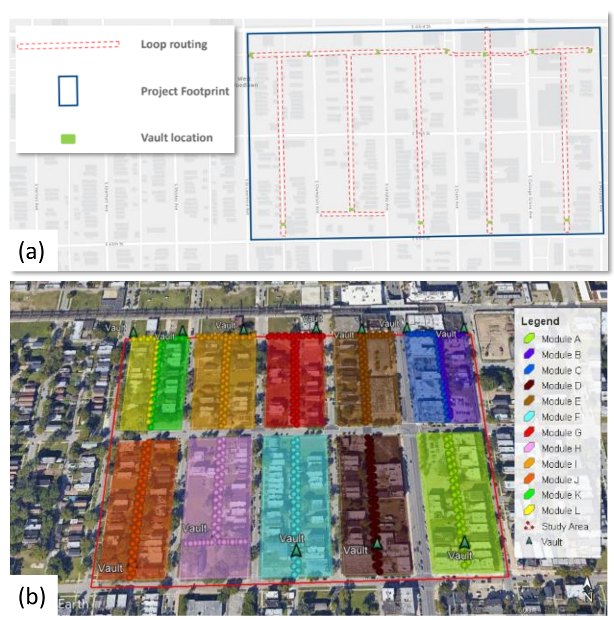

Fig. 2 *(a) Site footprint and proposed loop routing and vault location; (b) Proposed modules*

collect baseline household and community data, including energy and water use, bill data, building envelope and safety issues, as well as information on barriers to adoption of clean energy technologies. This information is used to estimate the thermal loads for the buildings in the neighborhood.

2.3 Subsurface Characterization

The subsurface stratigraphy was estimated using existing drilling logs for water wells and engineering test holes provided by the Illinois State Geological Survey (ISGS) and geologic map of the Jackson Park quadrangle (Curry et al., 2023). The boreholes used for the analysis are shown in Figure 3(a). A typical stratigraphic profile for the West Woodlawn neighborhood (assuming isotropic, homogeneous, and horizontal layers) is shown in Figure 3(b). Further fieldwork was performed to determine the depth of the bedrock and various laboratory analyses were performed to determine their thermophysical properties.

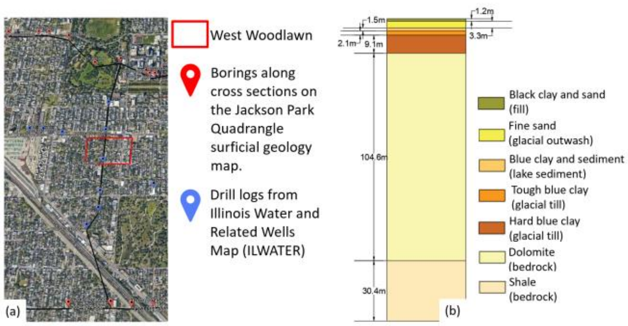

Fig. 3 *Existing boreholes in the West Woodlawn area; (b) Stratigraphic profile*

2.3.1. Field Work

Horizontal-to-vertical spectral ratio (HVSR) passive seismic data was acquired in the study area by the ISGS as part of an ongoing project to map the geology of Metropolitan Chicago. The HVSR method is used to estimate the depth of the bedrock (Karahalios et al. 2021), and in the study area the bedrock was found to be between 17.3 m and 19.3 m below ground surface.

Table 1. *Thermal conductivity values of core samples*

Sample ID	Thermal conductivity	Thermal diffusivity	Specific heat
	(W/mK)	(mm^2/s)	(MJ/mm^3K
C9985_62.6	3.86	2.17	1.78
C9985_75.3	3.61	2.67	1.36
C9985_99.3	4.59	0.8	5.76
C9985_120.85	3.47	2.17	1.82
C9985_132.4	3.25	2.46	1.32
C9985_160.4	4.46	0.57	7.95
C9985_195.75	4.89	0.43	11.4
C9985_245.2	2.28	0.47	5.12
C9985_292.3	4.08	0.35	11.7
C9985_292.65	1.39	0.26	5.37
C9985_306.7	1.44	0.49	4.33
C9985_322.65	2.35	0.62	7.20
C9985_343.2	2.61	0.98	6.30
C9985_394.4	2.25	0.43	6.49

2.3.2 Laboratory Analysis

Thermal property tests were performed to measure the thermal conductivity, thermal diffusivity, and volumetric heat capacity of core samples previously obtained in Metropolitan Chicago (Phillips et al. 2023) that are representative of subsurface below the West Woodlawn neighborhood. The apparatus is shown in Figure 4. A sample of the results are summarized in Table 1. Bulk density measurements of core samples of the unconsolidated sediments were determined following ASTM Standard D763-09(2018)e2 (ASTM, 2018). The thermophysical properties of the geologic materials are summarized in Table 2.

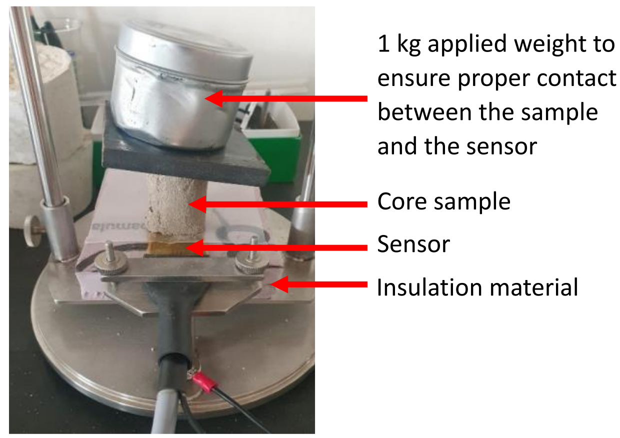

Fig. 4 *Laboratory procedure using HotDisk® thermal property analyzer*

3. EXISTING BUILDINGS AND THERMAL LOADS

Based on the data presented in Section 2, the heating and cooling loads were estimated and are summarized in Table 3. The hourly and daily heat loads of buildings A01 and A02 and shown in Figures 5(a) and 5(b), respectively.

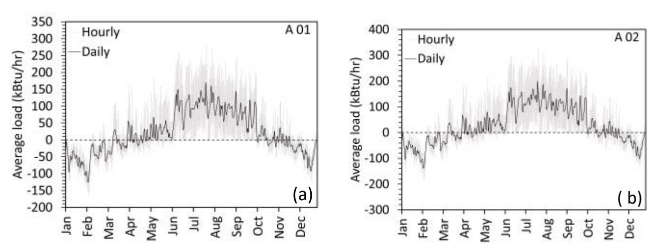

Fig. 5 *Hourly and daily energy loads for building (a) A01; and (b) A02*

Table 2. Thermophysical properties of geologic materials

Geologic material	Thickness	Bulk density, ρ	Thermal conductivity, λ	Thermal diffusivity, α	Specific heat capacity, C_p	Hydraulic conductivity, k	Porosity, n
	m	kg/m³	W/(mK)	mm²/s	J/(kgK)	m/s	-
Black clay and sand (fill)	1.2	1450	1.2	1.2	880	1.7×10^{-6}	0.35
Fine sand (beach deposits)	3.3	1500	0.8	4.0	1300	1.7×10^{-6}	0.35
Blue clay and sand (lake deposits)	1.5	1260	0.7	0.6	880	1.05×10^{-9}	0.41
Tough blue clay (Wadsworth till)	2.1	1200	1.6	1.3	1000	1.05×10^{-9}	0.15
Hard blue clay (Haeger till)	9.1	1700	2.1	1.3	850	1.05×10^{-9}	0.21
Dolomite (Racine Dolomite)	104.6	2830	4.5	1.0	879	1.04×10^{-12}	0.10
Shale Maquoketa Shale	30.4	2850	3.39	0.8	863	2.19×10^{-13}	0.15

Table 3. Module A: Building types, peak heating, and peak cooling loads

	$Q_{peak,heating}$	$Q_{peak,cooling}$	Building type
	W	W	
A01	36625	47998	Residential
A02	40305	58383	Residential
A03	21645	30682	Residential
A04	10087	17293	Potential future development
A05	8879	18417	Residential
A06	18425	23508	Residential
A07	20687	26747	Residential
A08	23717	29167	Residential
A09	14765	22317	Residential
A10	8403	22034	Residential
A11	8409	22918	Residential
A12	19065	38795	Residential
A13	61565	75441	Residential and Retail
A14	49350	56023	Residential and Retail
A15	75870	81009	Residential and Retail
A16	16016	47766	Potential future development
A17	24780	64725	Potential future development
A18	22390	59679	Potential future development

The simulation assumptions include the envelope insulation type, window SHGC and U-value, infiltration, internal load, and pump energy. A sensitivity analysis was performed considering the assumptions and the different situations will be tested in future analyses.

A preliminary design analysis was performed to size the shared community geothermal network using the methodology in Philippe et al. (2010), which superposes three thermal loads and estimates thermal resistances to find the minimum length of heat exchanger required to not exceed allowable limits of fluid temperature. The sizing equation is:

$$L = \frac{q_h R_b + q_y R_{10y} + q_m R_{1m} + q_{6h} R_{6h}}{T_m - (T_g + T_p)} \quad (1)$$

where L is the total borehole one-month), T_m is the mean fluid temperature (°C), T_g is the undisturbed ground temperature (°C), T_p is the temperature penalty to account for thermal interference between boreholes (°C), q_y represent yearly average ground load (W), q_m is maximum monthly ground load (W), q_h is peak hourly ground load (W), R_{10y} is the ten year effective thermal resistance (mK/W), R_{1m} is the one month effective thermal resistance (mK/W), R_{6h} is the six hour effective thermal resistance (mK/W), and R_b is the effective borehole thermal resistance (mK/W).

For Module A, based on the thermal loads and assumed fluid and borehole characteristics, a total of 68 boreholes with a depth of 150 m are needed to supply the heating and cooling needs of the 18 buildings.

4. CONCLUSIONS AND FUTURE WORK

This paper focused on the design of a community geothermal system in the West Woodlawn neighborhood. The proposed geothermal system is designed to evaluate and demonstrate an equitable and just transition to building decarbonization in dense and urban environments in temperate climates. This study holds a significant importance for several reasons. To name a few, this is one of the first research-integrated systems designed using advanced numerical tools; design charts are being developed for a community-scale geothermal system for the first time; and real-time monitoring and data collection are integrated in the design efforts. Next phases of this project focus on as follows:

- Development of a physics-based model to simulate the subsurface multiphysics processes including heat transfer and water flow;
- A parametric study that will be used to generate design charts as an "easy-to-use" tool that allows for the design of the other modules in the project footprint;
- A life cycle cost analysis assessment of the geothermal loop system based on current industry cost data; and
- Investigation of the environmental impact of the entire system.

The results of this study are specific to a Chicago neighborhood with a US Midwest region climate and geology. The design charts being developed will provide a straightforward tool that could be used in future designs elsewhere.

5. ACKNOWLEDGEMENTS

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