Technical, Economic, and Environmental Assessment for Ulbrich Heights Community Geothermal Heat Pump Project

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Executive Summary

This report presents the results of a study of the potential for clean onsite energy and energy efficiency technologies for Ulbrich Heights, an affordable housing community in Wallingford, Connecticut. The technical team, including University of Connecticut and LN Consulting, a mechanical electrical and plumbing (MEP) firm, evaluated a community geothermal heat pump (GHP) system consisting of a central geothermal system (central geothermal well field, pumphouse, and associated piping) plus a thermal distribution system (piping within the residential buildings and water-source heat pumps [WSHPs] in each apartment). The evaluation assesses GHP both with and without deployment of on-site photovoltaics (PV) and heat pump water heaters (HPWH). It also compares GHP with two basic alternative systems: distributed air-source heat pumps (ASHPs) and distributed geothermal heat pump (dGHP). Tables 1 through 3 summarize the results of the evaluation of these clean and energy-efficient technologies.

The estimates of net capital costs incorporate anticipated incentives from the federal Investment Tax Credit (ITC), Wallingford Electric Division (WED), and Yankee Gas. GHP is sized to meet the Ulbrich Heights facility's heating and cooling consumption as simulated in EnergyPlus and TRNSYS. HPWH is sized via extrapolation from summer heating loads. ASHP and dGHP are sized on the basis of degree-day heating and cooling, using monthly utility data. PV is sized with consideration of rooftop space available and the site's overall electric monthly electric load. Additional technologies such as sewer water heat recovery are considered but determined not to be feasible.

Equipment and Operation

The 38-building Ulbrich Heights affordable-housing complex is managed by Wallingford Housing Authority (WHA). With a portfolio of residential garden-style and duplex housing options, the 132,178 ft^2 of conditioned living space houses 132 tenant households (apartments). Monthly electricity consumption, gas consumption, and facility occupancy are shown in Figures 1 through 3. As shown in Figures 1 and 2, while electricity consumption has trended upward, gas consumption has an opposite trend. While the increasing trend in electricity consumption may be attributable to the increasing occupancy depicted in Figure 3, there is a slight downward trend of gas consumption that may be partly attributable to replacement of 15 of the facility's gas hot water heaters with electric resistance. The increasing trend in electricity consumption may partly be attributed to increased electric-resistance water heater load as well. As shown in Table 1, the tenants' annual energy consumption is approximately 810 MWh of electricity and 6,617 MMBtu of natural gas, at a total cost of \$230,186 and an average annual cost of \$1,744 per tenant (utility rates are \$0.1292/kWh for electricity and \$18.93/MMBtu for gas). As shown in Table 3, accounting for both on-site emissions and grid emissions, the residential facility is responsible for 603 tons of annual CO_2 emissions.

Each apartment in the complex employs a hydronic space-heating system with heat convectors controlled by a single-zone thermostat. Most apartments use one or more window air-conditioning units in bedroom and living spaces. WHA maintenance personnel repair or replace old/broken gas-fired boilers and domestic water heaters. WHA has replaced 15 of the domestic hot water heaters with electric resistance water heaters; and 22 of the newest apartments had electric-resistance water heaters installed during construction. Tenants own the cooling equipment, and repair and replacement of this equipment is their responsibility.

While WHA has no formal commitment to carbon emissions reduction, the agency has systematically improved the efficiency of the Ulbrich Heights buildings via WED's weatherization program and third-party value-added contractor network.

Modeling Parameters

The following considerations have informed the analysis:

- **PV** is a clean energy technology of significant interest because each Ulbrich Heights building has enough roof space for a significant installation. Approximately 60,311 ft^2 of roof space is available. Roof arrays would be preferable to land and parking lot canopies that would entail additional construction costs. The structural integrity and load-bearing capacity of the roofs have not been evaluated for this analysis.

- **HPWH** is a technology of interest because WHA has installed electric-resistance during the most recent construction of 17 percent of the facility's apartments and under the site's maintenance plan gas-fired water heaters for other apartments gradually are being replaced with electric-resistance equipment. Electric-resistance water heating is highly inefficient. Upgrading to more efficient HPWH units would bring significant tenant electricity savings as well as further reduction in the facility's natural gas consumption and site carbon emissions.

- **PV + HPWH** combines the benefits of these technologies. It would be expected to provide deeper reductions in site carbon emissions but at a significantly higher cost of implementation.

- **ASHP** is modeled as another technology solution for economic and environmental performance comparisons. It would provide emissions improvements against the baseline but not against GHP – at lower capital cost but higher operating cost than GHP.

- Similarly, a **dGHP** system – with an individual geothermal system for each building – was modeled as an alternative space heating and cooling technology solution for economic and environmental performance comparison.

- Additionally, sewer water heat-recovery, solar thermal, and thermal energy storage technologies were considered to supplement the GHP system in an early analysis. Sewer pipe locations and sewer flowrate data were obtained, but the sewer flowrates were highly intermittent and therefore sewer water heat recovery was not further considered in the design process. Also, since the estimated building heating and cooling loads were fairly balanced, it was concluded that adopting solar thermal or thermal energy storage could not reduce the size of the borefield.

The GHP system scenarios are based on building loads obtained from EnergyPlus, a building-energy modeling tool. The model the team developed accounts for the actual geometry of the buildings, which was derived from architectural drawings developed for a recent facility renovation plan. Building envelope properties such as wall R-values, window types, and air infiltration rates are inputs in the model, using data from a small sample of Home Energy audits performed by WED contractors. The team tuned the model to match the actual average billed energy consumption. The model incorporates schedules for lighting, interior loads such as appliances and hot water usage, and occupancy.

The following inputs and assumptions are used in the energy and economic performance calculations:

- Utility rates of $0.1292/kWh and $18.9276/MMBtu, with corresponding assumed annual escalation rates of 1.7% and 1.5%.

- System efficiency degradation rates of
    - 0.1% for GHP, dGHP, and HPWH;
    - 0.5% degradation for PV, ASHP, and pump equipment.

- For the ASHP scenario, 75% equipment replacement costs at years 10 and 20.

- Federal ITC for GSHP and solar PV is 30% plus 10% domestic-content bonus; WED incentives are $300/ton for GHP, $300/ton for ASHP, and $750/unit for HPWH, with no incentives for PV; Yankee Gas incentives are $740,000 for GHP, $750/ton for ASHP, and $750/unit for HPWH. The project team was unable to determine whether the facility would qualify for ASHP and HPWH incentives under the federal energy-efficient commercial buildings deduction program.

Clean Energy Technology Analysis Results

A summary of the analytical results that are presented in Tables 1, 2, and 3:

- A networked, community **GHP** system was sized to meet 100% of the heating and cooling loads derived from the utility data. It has a net capital cost of $4.7 million ($4.3 million incremental, i.e., beyond baseline cost of replacing existing boilers), reduces natural gas consumption for heating 77% against the baseline, increases electricity consumption 23%, reduces annual carbon emissions 41%, and yields a simple payback of nearly 80 years. The lifecycle cost (LCC) for a 30-year period is $8.6 million.

- The GHP system with HPWHs (**GHP+HPWH**) sized to meet the average domestic hot water load of approximately 118 MMBtu per month has a net capital cost of $5.2 million ($4.8 million incremental), eliminates natural gas needed for both space heating and hot water, increases electrical consumption 39% against the baseline, reduces annual carbon emissions 50%, and has a payback of 74 years.

- The GHP system combined with a 900 kW PV system (**GHP+PV**) has a net capital cost of $6.3 million ($5.9 million incremental), serves 81% of the annual facility electric load, reduces annual carbon emissions 81% against the baseline, and has a simple payback of 36 years.

- The GHP system combined with PV and HPWHs (**GHP+PV+HPWH**) has a net capital cost of $6.8 million ($6.4 million incremental), eliminates natural gas consumption, serves 73% of the annual facility electric load, reduces annual carbon emissions 90%, and has a payback of 36 years.

- The **ASHP** scenario has a net capital cost of $4.3 million ($3.9 million incremental), increases electrical consumption 42% against the baseline, reduces natural gas consumption 77%, reduces annual carbon emissions 34%, and has a payback of 110 years.

- A **dGHP** system has a net capital cost of $4.6 million ($4.2 million incremental), increases electrical consumption 25% against the baseline, reduces natural gas consumption 77%, reduces annual carbon emissions 40%, and has a payback of about 80 years.

- An analysis of **ASHP+PV+HPWH** was not specifically performed. Like the GSHP+PV+HPWH scenario, it would eliminate on-site fossil-fuel emissions. Its lifecycle cost would be significantly higher, however, due to ASHP's far higher lifecycle costs.

- Overall, **ASHP** technology solution has the lowest net implementation cost but also the highest payback (111 years) and the highest lifecycle costs (2.5 times that of GHP). Therefore, **community GHP** is a more suitable option even though it has a slightly higher net capital cost. However, the **GHP+PV+HPWH** combination of technologies offers an economically and environmentally attractive solution: although initially more expensive than GHP alone, it provides full-site decarbonization, yields a payback time and lifecycle cost that are nearly the lowest, significantly reduces tenant utility cost burden, and offers significant environmental benefits by further reducing carbon emissions, particulate (PM2.5) emissions, and NOx emissions. The differences between the network GHP system performance and the **distributed GHP** system performance are not significant. Though an analysis of **ASHP+PV+HPWH** wasn't specifically performed, this scenario would result in freeing the Ulbrich Heights property from fossil fuels; but the anticipated life-cycle costs would be higher than the GHP+PV+HPWH scenario, since ASHPs have a higher estimated life-cycle cost. And a final note: the central GHP borefield and a closed loop system would require that only a few trees be removed from the site.

Table 1: Annual Tenant Energy Consumption and Utility Costs[1]

	Baseline	GHP	GHP + HPWH	GHP + PV	GHP + PV + HPWH	ASHP	dGHP
Annual Electricity Consumption (kWh/year)	810,378	997,168	1,126,389	87,385	216,606	1,149,811	1,015,270
Annual Gas Consumption (MMBtu/year)	6,617	1,517	0	1,517	0	1,517	1,517
Annual Electricity Cost ($/year)	104,701	128,834	145,529	11,290	28,217	148,556	131,173
Annual Gas Cost ($/year)	125,485	28,954	246	40,244	246	28,954	28,954
Total Annual Utility Costs ($/year)	230,186	157,788	145,775	40,244	28,463	177,509	160,126
Annual Utility Cost Per Tenant ($/year)	1,744	1,195	1,104	305	216	1,345	1,213
Tenant Utility Cost Reduction ($/year)	-	548	639	1,439	1,528	399	531
Percentage Reduction	-	31%	37%	83%	88%	23%	30%

[1] Includes only tenant electric and natural gas consumption

Table 2: Other Economic Results

	Baseline[2]	GHP	GHP + HPWH	GHP + PV	GHP + PV + HPWH	ASHP	dGHP
Gross Capital Cost ($)	392,000	8,687,504	9,347,504	11,401,499	12,061,499	4,683,600	8,399,562
Utility Incentives ($)	-	845,000	1,043,000	845,000	1,043,000	367,500	845,000
Federal ITC ($)	-	3,137,002	3,137,002	4,222,600	4,222,600	-	2,982,225
Net Capital Cost ($)	392,000	4,705,502	5,167,502	6,333,899	6,795,899	4,316,100	4,572,337
Net Incremental Capital Cost ($)		4,313,502	4,775,502	5,941,899	6,403,899	3,924,100	4,180,337
Annual O&M Costs ($)[3]	-	156,942	189,942	174,942	174,942	304,700	138,500
Simple Payback (years)[4]	-	79.6	73.5	35.7	36.2	110.8	80.4
LCC ($; 30- yr)	-	8,606,547	6,605,196	9,922,442	6,682,315	21,505,849	7,752,355

[2] Baseline reflects WHA estimate of cost of staff replacement of existing boilers. [3] O&M costs covers both owner' costs and tenant costs. [4] Simple Payback is calculated as ratio of net incremental capital cost from baseline to annual energy cost savings

Table 3: Emission Results[5]

	Baseline	GHP	GHP + HPWH	GHP + PV	GHP + PV + HPWH	ASHP	dGHP
Annual Carbon Emissions (tons)	603	356	302	112	58	397	361
Percent Reduction	-	41%	50%	81%	90%	34%	40%
Annual NOx Emissions (lb.)	1,159.0	820.7	770.5	198.4	148.2	925.1	833.1
Percent Reduction		29%	34%	83%	87%	20%	28%
Annual PM2.5 Emissions (lb.)	85.7	56.9	51.7	15.1	9.9	63.9	57.7
Percent Reduction		34%	40%	82%	88%	25%	33%

[5] Estimated using current grid emission factors and onsite emission factors (source: NREL Reopt); estimates do not account for projected future Connecticut grid greening

Conclusion

This techno-economic and environmental study showed that a community geothermal system with WSHPs in each apartment (but retaining gas-fired water heaters) in the Ulbrich Heights affordable-housing facility in Wallingford, CT, would markedly reduce tenants' energy costs as well as emissions of CO_2, particulates, and NOx. A fully electrified solution incorporating GHP, PV, and HPWH would have lower lifecycle costs, offer even better environmental benefits, and further reduce energy cost burden on tenants. Alternative deployment of ASHPs would be cheaper initially but far more expensive than other options in the long term and would produce more modest reductions in emissions (and correspondingly larger demands on the grid). In this particular facility, deployment of distributed GHP, rather than centralized community GHP, would have comparable environmental results and modestly better economic results due to reduced network piping and elimination of the pumphouse. With the Connecticut electricity grid getting greener as the state progressively moves toward satisfying its statutory requirement for a zero-carbon grid by 2040, the environmental benefit of all of these electrification solutions would become more attractive year by year.

A significant barrier for the GHP technology scenarios for this facility is the initial cost of implementation, which remains high even after state and local clean energy incentives and results in long payback periods. This barrier would be expected to be less significant in a community or facility with more diverse thermal loads and especially with available sources of waste heat, because this would reduce the required borefield capacity (and borehole drilling is one of the most expensive aspects of GHP installation). It should be noted that this study addresses an issue that has gotten relatively little attention in the technical literature: comparing the costs of networked geothermal heat pump systems and those of distributed geothermal heat pump systems.

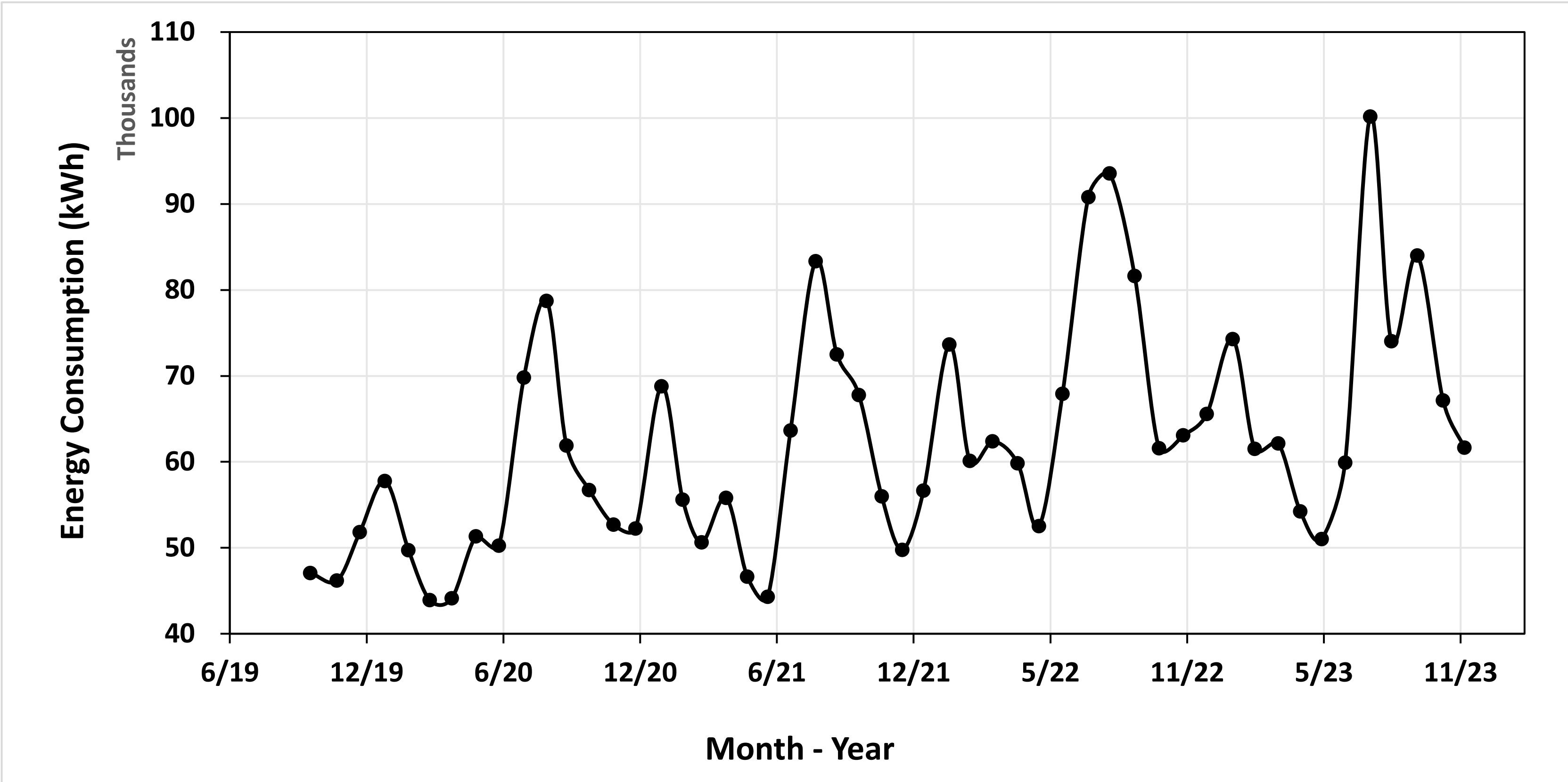

Figure 1. Ulbrich Heights monthly electricity consumption

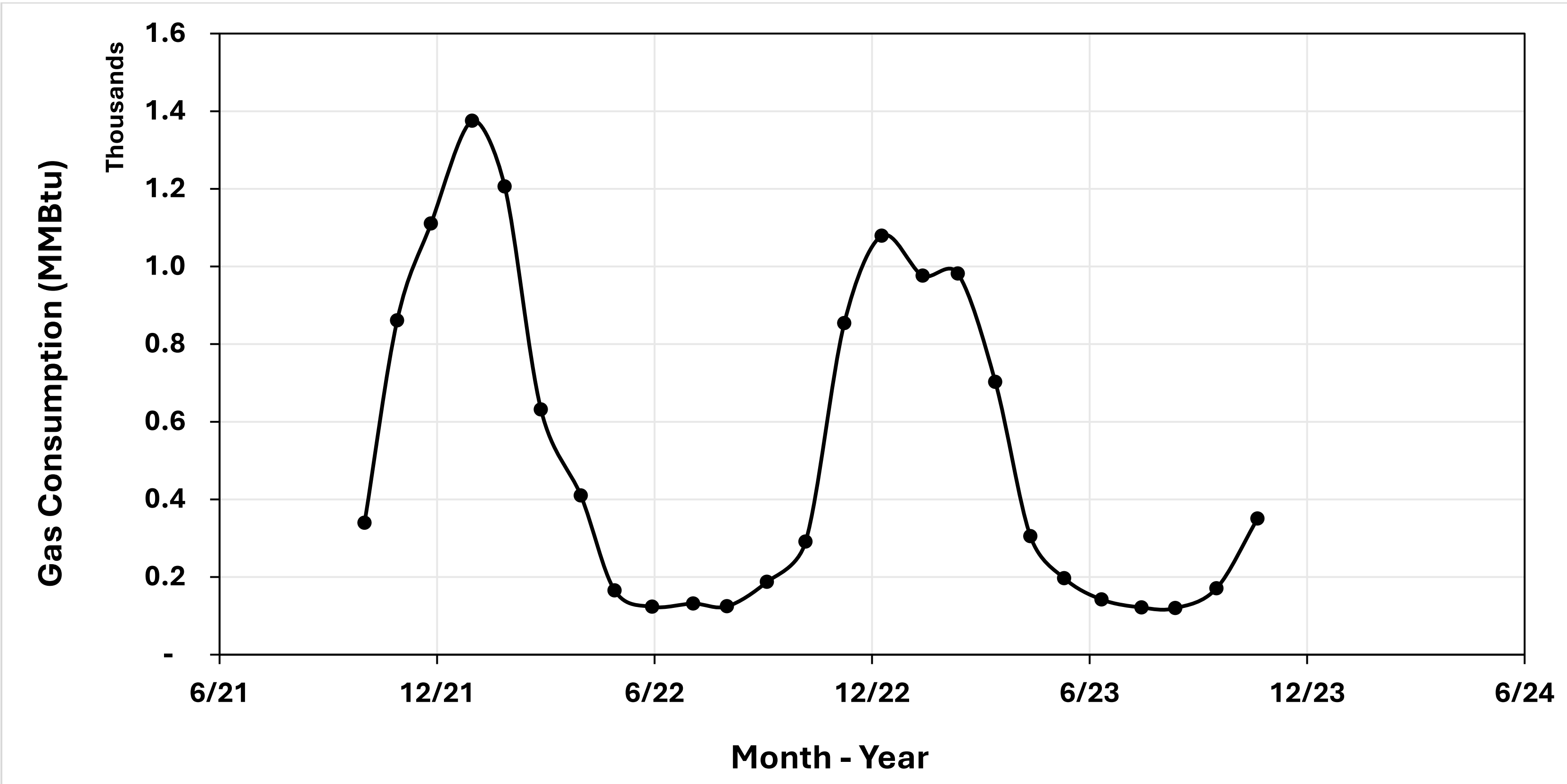

Figure 2. Ulbrich Heights monthly natural gas consumption

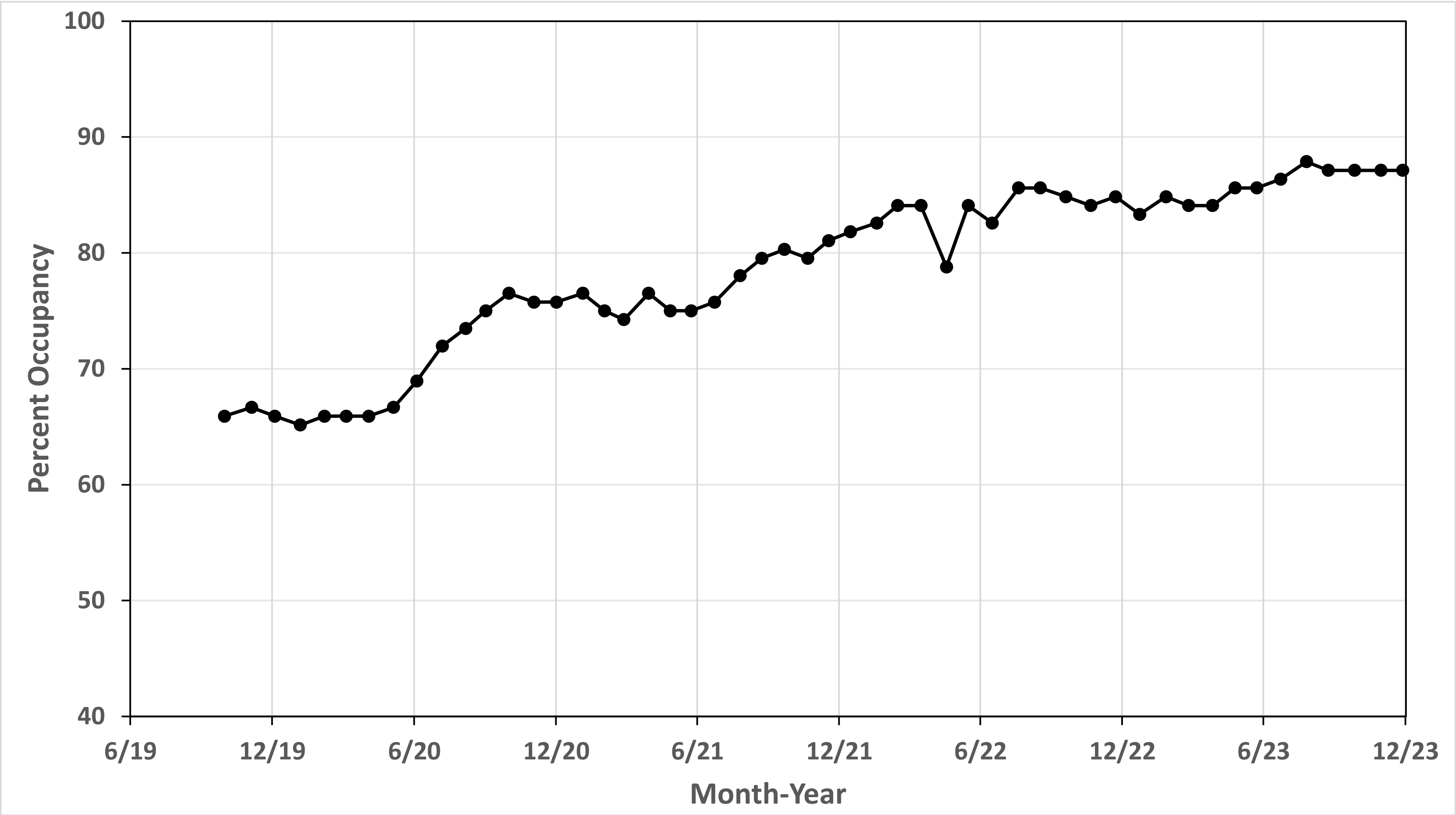

Figure 3. Ulbrich Heights monthly tenant occupancy