Review of NYSERDA's Community Heat Pump Systems Feasibility Studies

(Program Opportunity Notice 4614)

Final Report | Report Number 24-21 | April 2024

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Final Report

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NYSERDA Report 24-21 NYSERDA Contract 211327 April 2024

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Preferred Citation

New York State Energy Research and Development Authority (NYSERDA). Year of publication. "Review of NYSERDA's Community Heat Pumps Systems Feasibility Studies (PON 4614)," NYSERDA Report Number 24-21. Prepared by Meline Engineering Corporation, Sacramento, CA, and GWA Research, LLC, Lyme, NH. nyserda.ny.gov/publications

Abstract

This report summarizes and synthesizes the learnings of Program Opportunity Notice (PON) 4614 to share with external stakeholders, as well as inform future program design and policy development that supports New York State's Climate Leadership and Community Protection Act (Climate Act) goals.

Keywords

Community heat pump systems, thermal energy networks, ambient temperature loop, borehole heat exchanger, district energy systems, geothermal heat pumps, ground-source heat pumps, central plant, distributed heat pumps, ground loop, ground heat exchanger, feasibility study, life-cycle cost analysis

Acknowledgments

The authors of this report appreciate the opportunity to assist NYSERDA with the continuous improvement of their funding and reporting process in support of district energy systems which incorporated new possibilities and allow for innovation using ground-source heat pumps and other renewable technologies.

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Acronyms and Abbreviations

$/ft	dollars per foot
$/lf	dollars per linear foot
$/m	dollars per meter
°C	degrees Celsius
°F	degrees Fahrenheit
°K	degrees Kelvin
°R	degrees Rankine
ACOP	average coefficient of performance
AHRI	Air-Conditioning Heating and Refrigeration Institute
ANSI	American National Standards Institute
ASHP	air-source heat pump
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
ASTM	American Society of Testing Materials
ATL	ambient temperature loop
BAS	building automation system
BHX	borehole heat exchange
BLCC	Building Life-Cycle Cost
Btu	British thermal units
Btu/hr	British thermal units per hour
Btu/hr-ft-°F	British thermal units per hour per foot per degree Fahrenheit
CHPS	community heat pump system
CHW	chilled water
Climate Act	Climate Leadership and Community Protection Act
CO2	carbon dioxide
COP	coefficient of performance

CP	central plant
CSA	Canadian Standards Association
CT	cooling tower or closed-circuit fluid cooler
DAC	disadvantaged communities
DC	district cooling
DEC	New York State Department of Environmental Conservation
DH	district heating
EER	energy efficiency ratio
ER	electric resistance heaters, boilers, or domestic hot water heaters
ETS	energy transfer stations
EU	European Union
EWT	entering water temperature
FHX	foundation heat exchange
ft	feet
ft/ton	feet per ton
ft^2/day	square feet per day
GHX	ground heat exchange
GSHP	ground-source heat pump
GWP	global warming potential
HDPE	high-density polyethylene
HRC	heat recovery chiller
HVAC	heating, ventilation, and air conditioning
HW	hot water
HX	heat exchanger
IDEA	International District Energy Association
IEER	integrated energy efficiency ratio
IGSHPA	International Ground Source Heat Pump Association
IHC	integrated heating capacity
in	inch
ISO	International Organization for Standardization
kft^2	thousand square feet
kg/sec	kilograms per second
kW	kilowatt
kWh	kilowatt hours
LCCA	life-cycle cost analysis
lf	linear foot
LL97	New York City Local Law 97
LMI	low- to moderate-income
M	meters

M	million
MF	multifamily
MMBtu	million British thermal units
MW	megawatts
NG	natural gas or propane
NIST	National Institute of Standards and Technology
NP	not provided
NPV	net present value
NYS	New York State
NYSERDA	New York State Energy Research and Development Authority
NYSJU	New York State Joint Utilities
O&M	operations and maintenance
OLGW	open-loop groundwater heat exchange
PON	program opportunity notice
psi	pounds per square inch
PV	photovoltaic
R&D	research and development
RFO	renewable fuel oils
S&R	supply and return
SEL	Schweitzer Engineering Laboratories
SHX	sewer heat exchanger
sf	square foot
ST	solar thermal
STG	staggered borehole layout
SWHX	surface water or stormwater heat exchange
TC	thermal conductivity
TES	thermal energy storage
TSPR	total system performance ratio
UL	Underwriters Laboratories
VRF	variable refrigerant flow
VRV	variable refrigerant volume
W	watts

Executive Summary

After reviewing the first 20 feasibility studies completed by solution providers through the program opportunity notice (PON) 4614 and in consultation with the New York State Energy Research and Development Authority (NYSERDA), the following four areas are recommended for standardization in future feasibility studies. This standardization will facilitate fair comparisons of proposed projects for economic analysis and financing.

1. Life-cycle cost analysis inputs
2. System energy efficiency
3. Design metrics
4. Planning for resiliency

In addition to these standardization recommendations, Section 3 of this report provides guidance on building efficiency, available software tools for design, general recommendations for future thermal energy network PONs, including communication of design information, and preferred terminology for these systems.

The common industry terminology for the projects discussed is district energy systems. Current terms such as "community heat pump systems" and "thermal energy networks" fall under the definition of district energy systems.

After analyzing the feasibility studies and conducting interviews with solution providers, the following characteristics contribute to the potential adoption of thermal energy networks for heating and cooling multiple buildings:

- New construction
- In-building heat delivery systems compatible with low supply temperatures (i.e., radiant panels)
- A client decision to implement all-electric systems, driven by a desire to reduce fossil fuel use or meet external requirements; a corporate directive may also necessitate using an all-electric mechanical system, specifically, geothermal heat pumps
- Minimal grid impact or sufficient local electrical capacity
- Alignment of the project development schedule with opportunities for co-funding or other financial incentives, or disincentives to business-as-usual, such as New York City Local Law 97 (LL97)
- Building owners, including government entities (e.g., U.S. Department of Defense), higher education campuses, and municipalities, willing to accept longer payback periods

- Clear opportunities to integrate heat sources or sinks with thermal energy networks, such as treated wastewater discharge into lakes
- Existing gas-fired mechanical heating, ventilation, and air conditioning (HVAC) equipment nearing its useful life and requiring replacement, either in buildings or at the central plant (e.g., absorption gas chillers on college campuses)
- Integration potential with large public infrastructure projects, including water or sewer pipe replacements or relocation, highway rerouting, and separation of sewer and stormwater piping systems
- Multiple buildings under common ownership
- Projects aiming to eliminate open or forced-draft cooling towers due to concerns about Legionella
- Project sites located in areas without natural gas infrastructure

Additional insights from solution providers during interviews include:

- Solution providers seek opportunities to partner with public projects. Deferred maintenance on energy projects serves as a motivating factor, because energy savings can fund replacements, retrofits, or renovations. For district systems, significant costs arise from trenching for retrofits. Partnering with other projects can help share or eliminate these costs.
- Recent changes in drilling depth limits, previously set to 500 feet (ft) and now removed (N.Y. Senate, 2023), may lower drilling costs since deeper drilling at each site becomes possible. Designers must evaluate the local hydrogeology and buried infrastructure.
- The industry requires increased drilling capacity due to high demand and low availability.
- Overall, solution providers perceive good support from NYSERDA and other agencies in addressing technical and regulatory challenges projects face. While some regulators do not respond as quickly as desired, providers recognize that the feasibility phase allows time to address details if a project moves into design.

1 Introduction

1.1 Background

The installation of the first district heating system in the U.S. occurred in 1853 at the U.S. Naval Academy in Annapolis, MD, and used steam. Birdsell Holly invented the first commercial district heating system in Lockport, NY, in 1877, which operated for 92 years before shutting down in 1969 (Phetteplace et al., 2013, p. 1.1).

Since then, many cities, power companies, and private companies have installed both district heating and district chilled water systems in locations where such investments proved cost-effective and profitable. Although the early development of these systems originated in the U.S., Europe quickly surpassed it with widespread adoption of steam and hot water district heating. Currently, district cooling experiences the largest growth in Europe, the Middle East, and Asia (Tredinnick and Phetteplace, 2016, p. 167–188). In response to climate change and the rising demand for comfort air conditioning in developing countries, district cooling will likely continue to grow rapidly. Furthermore, the movement to decarbonize the economy and reduce greenhouse gas emissions challenges developers and designers to find more energy-efficient heating and cooling methods. District energy systems offer unique opportunities to meet these goals. However, typical central-plant–based systems suffer from heat losses and gains in their distribution systems. Systems driven by clean electricity may use either central heat pump plants operating at lower hot water temperatures or distributed heat pumps within the buildings, both classified as district energy systems or thermal energy networks. To achieve reasonable coefficients of performance in space heating with heat pumps, heat delivery must occur at low temperatures. Existing building stock and systems may not always support this requirement. When replacing existing building equipment, it must operate at these lower heating temperatures; otherwise, the capital costs can escalate beyond what many investors consider a reasonable return on investment.

For new projects, adopting an all-electric system presents fewer challenges initially. However, ensuring that the local electric power grid can accommodate the additional electrical load remains a concern. For this reason, a resiliency study or plan should accompany project proposals to the New York State Energy Research and Development Authority (NYSERDA) for funding.

Whether the project is new or retrofit, connecting buildings in a thermal energy network can become cost prohibitive. Society must recognize that investments in these systems are long-term commitments. This approach has allowed district heating systems to flourish in Northern Europe, especially the Scandinavian countries. The expected lifespan used in pro forma and economic analyses for thermal energy networks should shift from 15–25 years to 50–100 years, similar to utility distribution systems, bridges, and other infrastructure. Many of these projects will require funding from the government or institutions with a long-term outlook, such as established and well-endowed universities and federal agencies. For example, the U.S. Department of Defense manages approximately 6,000 miles of district heating piping (Segan and Chen, 1984, p. 1). In the private sector, investors typically expect a higher minimum acceptable rate of return compared to what a utility or municipality might consider acceptable. The National Institute of Standards and Technology (NIST) sets an annual discount rate for evaluating energy efficiency and renewable energy projects for federal facilities. As of September 2023, the real rate of 3% is discounted with 0.2% inflation to 3.2% (Kneifel and Lavappa, 2023, p. 1). For a project to be profitable for investors, the adjusted rate of return for a life-cycle cost analysis (LCCA) must exceed 3.2%. Conversely, whereas the federal government seeks a rate of return that makes the net present value (NPV) of all investments in a project equal to zero, developers aim for a return on investment and typically seek adjusted rates of return between 5% and 10%, or even higher.

While incentives may encourage the adoption of less capital-intensive technologies, current constraints on these incentives may not be enough for thermal energy network systems. The return on investment for these systems may not materialize quickly, except for projects with access to unique resources. For those not inherently driven to reduce greenhouse gas emissions, implementing “disincentives” in the form of taxes or fees on carbon emissions will become necessary.

Another significant impediment to adopting thermal energy networks lies in unfamiliarity with the technology. NYSERDA’s development of program opportunity notice (PON) 4614, Community Heat Pump Systems, has funded nearly 50 feasibility studies that identify numerous opportunities for deploying thermal energy networks in New York State. While the results of this program will answer many questions, they will raise many more, as we will detail later.

As more community heat pump systems or thermal energy networks emerge from NYSERDA’s PON 4614 and subsequent efforts, a foundation for successful design, construction, and operation of these systems will emerge. Ultimately, transforming the knowledge gained into standards and design guides, and identifying necessary research and development (R&D) will enable widespread deployment of these systems.

1.2 Objective and Approach

This report summarizes and synthesizes the learnings from PON 4614 to share with external stakeholders and inform future program design and policy development that supports New York State's Climate Leadership and Community Protection Act (Climate Act) goals. The summary draws on a review of the first 20 feasibility studies completed under PON 4614, along with insights gained from interviews conducted with five solution providers involved in these studies. The interviews discuss the results of the feasibility studies and gather any necessary additional information. The findings from these interviews are integrated into this final report.

1.3 Synopsis of Program Opportunity Notice 4614 Feasibility Studies

Table 1 summarizes the top-level characteristics of the 20 feasibility studies in no order of prioritization. The order generally reflects the order in which draft and final reports were submitted to NYSERDA. The studies encompassed a wide range of building use types, ownership types, total project square footage, number of buildings served, and distinctions between new construction and retrofits. Most projects, specifically 18 out of 20, relied on multiple types of heat sources and sinks. Of the 20 projects, 16 used borehole heat exchanger (BHX) as a geothermal heat source or sink to satisfy at least part of the requirements. Other frequently chosen options included 8 air-source heat pumps (ASHP), 6 cooling towers (CT), 5 sewer heat exchange (SHX), 4 surface or stormwater, 3 solar thermal (ST), and 2 foundation heat exchanger (FHX). Seven sites met all or part of their energy load using conventional sources, such as electric resistance heating of air or water, while 5 sites used combustion of natural gas.

Table 1. Summary of the Principal Attributes of the Program Opportunity Notice 4614 Feasibility Studies

Project	Location	Development Type	Protect Type	DAC	Bldg. Area (kft2)	Ownership Type
Eastern Emerald Group	Queens	25-story tower that includes assembly spaces, office space, retail, restaurants, 256 hotel rooms, and 196 apartments	New construction enrolled in brownfield cleanup	No	637	Single owner
The Peninsula	Bronx	740 affordable housing units, daycare center, businesses, higher education and career readiness center, and health and wellness center	New construction in process	Yes	542	Joint venture
Silo City	Buffalo	Adaptive reuse of 6 historical buildings with approx. 400 apartments and more than 40,000 sf. of mixed-use spaces with diverse uses, from a sound stage to a hydroponic farm	Retrofit of site with potential contamination	Yes	562	Single owner
Pratt Landing	New Rochelle	Retail stores, grocery store, 660 residential units, and conference and performing arts center	New construction on brownfield site	No	802	Single owner
Wagner College	Staten Island	College campus	Retrofit	No	382	Single owner
Willets Point	Queens	Phase 1A: 3 residential buildings with 1,100 units of affordable housing and a 450-seat school. Phase 1B will include 6 additional buildings with residential, retail, and critical facilities	New construction on brownfield site	No	1,071	Single owner
Innovation Queens	Queens	3,000 apartments (725 affordable housing), commercial businesses, arts culture hub, and health and wellness facility	New construction	Yes	3,122	Multiple joint venture partners will own different blocks of the project
Syracuse District Energy System	Syracuse	Commercial, residential, and government. 34 potential customers. Includes existing Onondaga County district heating and cooling plant	Retrofit with expansion on site with potential contamination	Yes	2,115	Multiple owners, some owners with multiple buildings
Sheridan Hollow	Albany	147 potential neighborhood properties (houses, apartment buildings, church, convenience store, office, warehouse), existing Office of General Services. Included 6 condemned buildings and 36 empty lots for future development	Retrofit with brownfield on portion of site	Yes	448	Owner-operator system, or privately-owned thermal energy resource distributed by a utility
SUNY Oswego	Oswego	Retrofit the existing dining hall, office, and two dormitories currently served by district steam and chilled water	Retrofit	No	164	Single owner

Table 1. (continued)

Project	Location	Development Type	Protect Type	DAC	Bldg. Area (kft^2)	Ownership Type
Syracuse University	Syracuse	South Campus cluster includes data center, 2 office buildings, skating pavilion, student center, ski lodge, 2 apartment buildings with 20 units	Retrofit	Yes	303	Common ownership: design, bid, build
City of Troy District Energy	Troy	Phased development: 9 potential buildings on the north waterfront, including high and midrise apartments, and retail and office buildings. Next 12 buildings on the southern part of downtown centered around Russell Sage College. Phase 2 is a further build-out of phase 1 areas. Phase 3: redevelopment of the Troy waterfront	Redevelopment of site with new construction and retrofit	Yes	1,261	Utility: city to own loop/HX, building owners own their equipment
Children's Village Community	Dobbs Ferry	60 buildings with a diverse mix of administration, medical, recreational, educational, and residential spaces	Retrofit of existing campus	No	448	Intent is design, build, operate, own, and maintain
Downtown Utica CHPS	Utica	Mixed-use of 8 existing buildings; uses include library, theatre, office, auto repair, and education	Retrofit of historic downtown district	Yes	235	Suggested is municipal
Buffalo Training Center & Residences	Buffalo	Workforce training center and 11 residences	Retrofit	Yes	252	Not clear; believed to be the gas utility
Gowanus Green	Brooklyn	6 residential buildings with 950 units, retail space, community space, and a school	New construction on brownfield site	No	971	Partnership: design, bid, build.
Masonic Care	New Rochelle	Former educational campus, transitioning to mixed-use of higher education, community athletics, meeting space, offices, and assisted living center	Retrofit of former educational campus	No	803	Owner to engage Siemens in engineering, procurement, and construction
Phelps Hospital	Sleepy Hollow	Health care	Heat recovery chiller retrofit	No	465	Site owner
Pratt Institute	Brooklyn	Educational campus	Retrofit of existing campus	No	1,780	Site owner
Saranac Lake	Saranac Lake Village	Office, multifamily, hotel, and retail space	Retrofit of existing village	No	819	Not yet determined, likely municipal

2 Findings

2.1 Heat Sources and Sinks

Thermal energy networks can use a variety of heat sources and sinks. The feasibility studies conducted under PON 4614 examined several options, but many were not suitable for the studied sites due to factors such as availability, cost, technical readiness, or alignment with goals of the Climate Act.

Table 2 breaks down the sources and sinks included in the recommended approaches of the 20 feasibility studies. The data indicate that most of the proposed solutions will significantly impact the electric grid. Many projects involve new construction that aims to reduce carbon impacts by using electric technologies for heating, cooling, and domestic hot water heating. Similarly, for most of the retrofit projects, electricity is displacing other fuels that were being used primarily for space heating and domestic hot water heating. Only a few projects that already use electricity for cooling and, in some cases heating, have a negative grid impact. In these instances, shifting from less efficient technologies, such as air-cooled space cooling and geothermal source space cooling, decreases the grid impact.

Table 3 summarizes the uses of sources and sinks across all studies. The dominance of BHX and their derivative applications, such as foundation heat exchanges, directly stem from their widespread and successful adoption by the geothermal heat pump industry. Established design approaches for these systems contribute to a high comfort level across various applications. Unfortunately, however, some PON 4614 studies applied rules of thumb and other simplified sizing design approaches inappropriately. These simplified sizing design approaches should remain limited to residential applications in well-understood, localized geologies, and their use in larger applications within the PON 4614 studies misapplies effective design principles.

Table 2. Types of Heat Sources and Sinks Provided and Electric Grid Impact

Project	Location	New Construction or Retrofit	Total Bldg. Area (kft^2)	Sources and Sinks (in likely order of predominance)	Electric Grid Impact
Eastern Emerald Group	Queens	New	637	BHX, ASHP	Increased
The Peninsula	Bronx	New, already under construction	542	ASHP, BHX, NG, ER	Increased
Silo City	Buffalo	Retrofit	562	BHX, NG, ST	Increased
Pratt Landing	New Rochelle	New	802	SHX, BHX, ASHP, ER	Reduced
Wagner College	Staten Island	Retrofit	382	BHX, ASHP	Annual offset with solar PV possible
Willets Point	Queens	New	1,071	FHX, ASHP, ER	Increased
Innovation Queens	Queens	New	3,122	BHX, ASHP, ER, CT, SHX	Increased
Syracuse District Energy System	Syracuse	Retrofit and extension	2,115	SHX, SWHX, CT, ER	No change in buildings, new central plant load
Sheridan Hollow	Albany	Retrofit	448	BHX, ST, SWHX, ER, NG	Increased
SUNY Oswego	Oswego	Retrofit	164	BHX, NG	None
Syracuse University	Syracuse	Retrofit	303	BHX, CT	NP
City of Troy District Energy	Troy	New and retrofit	1,261	BHX, SWHX, SHX	Increased
Children’s Village Community	Dobbs Ferry	Retrofit	448	BHX	Increased
Downtown Utica CHPS	Utica	Retrofit	235	BHX, ER, ST	Reduction
Buffalo Training Center & Residences	Buffalo	Retrofit	252	BHX, NG	Increased
Gowanus Green	Brooklyn	New	971	FHX, ASHP, ER	Increased
Masonic Care	New Rochelle	Retrofit	803	BHX, CT, NG	Increased
Phelps Hospital	Sleepy Hollow	HRC retrofit	465	NA[a]	Increased
Pratt Institute	Brooklyn	Retrofit	1,780	BHX, ASHP, OLGW, CT, NG	Increased for all 8 options
Saranac Lake	Saranac Lake Village	Retrofit	819	BHX, SWHX, CT	Increased

[a] Phase 1 includes a heat recovery chiller (HRC) as an energy efficiency measure. The HRC serves the base cooling load, with recovered heat supplying a portion of heating loads; the remainder is served by natural gas boilers. In phase 3, additional heat loads are served by “booster” heat pumps.

Table 3. Summary of Sources and Sinks Proposed across All Studies

Heat Source or Sink	Abbreviation	Number of Studies Proposing
Borehole heat exchange	BHX	16
Air-source heat pumps	ASHP	8
Electric resistant heaters, boilers, or domestic hot water heaters	ER	7
Natural gas or propane	NG	6
Cooling tower or closed-circuit fluid cooler	CT	6
Sewage heat exchange	SHX	5
Surface or stormwater heat exchange	SWHX	4
Solar thermal	ST	3
Foundation heat exchange	FHX	2
Open-loop groundwater heat exchange	OLGW	1

Table 4 summarizes BHX data and assumptions from the 16 feasibility studies proposing that method. The parameters included in Table 4 are essential for making even a preliminary assessment of the required BHX, yet several studies either reached conclusions without fully appreciating the importance of these parameters or failed to disclose them in their reports. In either case, the creditability of the studies diminishes due to the absence of complete data on the BHX. Nonetheless, the data provided should serve as good metrics for others considering BHX installations in New York State. For example, the BHX installed costs ranged from a low of $35 per linear foot (lf) to a high of $62.75/lf, a range that reflects the wide variation in site conditions affecting costs. Additionally, the timing of these studies spanned from early 2021 to sometime in 2023, which should also be considered when evaluating costs. The average BHX cost was almost exactly $50/lf.

Following BHX, ASHPs were the next most popular heat source and sink. More accurately, outdoor air serves as the heat source or sink for this technology, along with cooling towers (or closed-circuit fluid coolers). In many feasibility studies, ASHPs functioned as supplements to the geothermal heat pump systems in a hybrid approach. Depending on the planned sequence of operation, ASHPs served as either the primary or secondary source of heat.

Table 4. Borehole Heat Exchanger Data Summary

Project	Location	Temp. Range for BHX[a] (°F)	Thermal Prop. Test	Undisturbed Ground Temp. (°F)	Thermal Cond. (Btu/hr-ft-°F)	Thermal Diff. (ft2/day)	Grout Thermal Cond. (Btu/hr-ft-°F)	BHX Spacing (ft)	BHX Depth (ft)	Number of Bores	BHX Loading (ft/ton)	BHX Cost ($/ft)	Notes
Eastern Emerald Group	Queens	30/90	Yes	56	1.26	0.84	1.20	20	325	180	162.5	$43.17	Borefield cost includes manifold
The Peninsula	Bronx	40/90	No	52	1.89	1.1	1.4	20’	500	Bldg. 2: 55 bldg. 3: 41	274	$62.75	
Silo City	Buffalo	E36/L30	No	52	1.89	1.1	1.4	20’	500	160	NP	$58.38	
Pratt Landing	New Rochelle	E36/L30	No	52	1.89	1.10	1.60	20’	500	120	NP	$54.50	
Wagner College	Staten Island	E36/L30	No	53	1.4	1.0	1.4	20’	500	139	NP	$61.36	
Innovation Queens	Queens	E36/L30	No	52	1.4	1.0	1.4	20	500	464	NP	$47.55	
Sheridan Hollow	Albany	32/90	No	53	1.28	0.8	1.6	25	500	256	200	$49.56	
SUNY Oswego	Oswego	32/77	Yes	52.3–54.2	2.28	1.39	NP	20	500	289	NP	NP	
Syracuse University	Syracuse	32/77	Yes	52	1.54	1.02	1.2	20	400	210	125	$37.50	
City of Troy District Energy	Troy	NP	No	NP	1.3	0.55	1.2	15 STG*	500	150 244 230 440	217	$50.00	Number of bores is listed in order for phases 1A, 1B, 2, and 3
Children’s Village Community	Dobbs Ferry	35/87	No	56.8	1.8	1.73	1.0	20	500	280	128	$35.00	Lateral piping at $20/lf and connection to ATL at $50-60/lf
Downtown Utica	Utica	45/55	No	50	NP	NP	1.56	NP	500	80	167	NP	

Table 4. (continued)

Project	Location	Temp. Range for BHX[a] (°F)	Thermal Prop. Test	Undisturbed Ground Temp. (°F)	Thermal Cond. (Btu/hr-ft-°F)	Thermal Diff. (ft^2/day)	Grout Thermal Cond. (Btu/hr-ft-°F)	BHX Spacing (ft)	BHX Depth (ft)	Number of Bores	BHX Loading (ft/ton)	BHX Cost ($/ft)	Notes
Masonic Care	New Rochelle	Two: 47/89; 48.7/84.4	No	NP	NP	NP	1.2	15-20	500	146	217	NP	
Pratt Institute	Brooklyn	30/90	Older borehole used	58	1.4	1.05	1.2	20	500	NP	NP	$50.00	20 ft spacing for vertical bores. Horizontal borefields spaced, at 15 ft vertically, 5 ft horizontally
Saranac Lake	Saranac Lake	NP	No	NP	NP	NP	1.2	20, or 15 STG*	495	NP	200	NP	

[a] When temperatures at BHX were provided, the format used was “min/max”; for heat pump temperatures, the format was “E, entering temp/L, leaving temperature.”

For the climate of much of New York State, outdoor air is a marginal heat source in winter. While ASHP technology is capable of functioning at temperatures well below freezing, efficiency decreases due to the Second Law of Thermodynamics, which applies to all heat pumps.

A straightforward expression for heat pump performance limitations based on source and sink temperatures, derived from a Second Law analysis, is the Carnot expression for coefficient of performance (COP):

Equation 1.

$$\boldsymbol{COP_h = \frac{T_h}{T_h - T_c}}$$

$$\boldsymbol{COP_c = \frac{T_c}{T_h - T_c}}$$

where:

- COP_h = Carnot COP in heating (dimensionless)
- T_h = Absolute temperature of the hot source or sink (°R or °K)
- T_c = Absolute temperature of the cold source or sink (°R or °K)
- COP_c = Carnot COP in cooling (dimensionless)

The limitations the Carnot COP imposes provide valuable insights for comparing ASHPs and ground-source heat pumps (GSHPs) under typical winter operating conditions, as illustrated on the temperature scale in Figure 1.

Figure 1. Comparative Performance Metrics of Ground-Source Heat Pumps and Air-Source Heat Pumps

For GSHP: $COP_h = T_h/(T_h - T_c) = (115+460)/(115-35) = 7.2$
Estimated Relative Cycle Efficiency = 0.60
Estimated Net COP = 4.3

For ASHP: $COP_h = T_h/(T_h - T_c) = (115+460)/(115+10) = 4.6$
Estimated Relative Cycle Efficiency = 0.50
Estimated Net COP = 2.3

Temperatures (F)

Refrigerant	Air to Room	Ground	Ground Loop Water	Refrigerant	Outdoor Air	Refrigerant
115	105	45	40	35	0	-10

(not to scale)

The higher temperature lift that ASHPs must overcome compared to GSHPs results in a COP that is slightly more than half that of GSHPs. Note that the temperatures and relative cycle efficiencies presented in this example reflect realistic conditions, but they do not represent actual measurements.

In addition to the penalty resulting from additional temperature lift, below-freezing temperatures require defrosting of outdoor heat exchangers. High humidity and temperatures near or below freezing will increase the frequency of this requirement more than expected. According to Kavanaugh, these impacts do not appear in advertised COP values:

> In defrost, units are switched to the cooling mode, which heats the outdoor coils to melt the accumulated frost. Electric resistance heat is activated during this period to provide “tempering” heat to maintain indoor temperature. However, the electric power/energy used to provide tempering heat is not included in the resulting COP values. Furthermore, the IHC [integrated heating capacity] values do not include the energy use required to melt additional snow or freezing rain. Values also do not include the auxiliary heat power/energy necessary when the heat pump capacity is less than the building heat loss. (2022, p. 4)

ASHP technology, for these reasons, will aggravate the problem of grid capacity during peak/near-peak heating conditions.

Where ASHPs and GSHPs or geothermal heat pumps combine to meet the load, several solution providers discussed an operational strategy that runs the ASHP preferentially during milder weather conditions, without relying on the GSHPs. This strategy emerged during the interviews conducted as part of the review process with solution providers, highlighting the importance of proposers explaining how they envision hybrid systems operating. Proposers claimed that this approach would effectively reserve the ground-source system for times when extreme conditions render the ASHP operation inefficient or unavailable. On the surface, this strategy appears beneficial, but it should be supported by design calculations for the ground-source system. If the ground-source system is not sized for the full annual load and design condition, it will respond with lower entering water temperatures (EWT) at these higher-than-design loads. That may necessitate antifreeze use where it otherwise might not be needed. Additionally, performance degradation may occur from the GSHPs due to lower entering water temperatures, but this degradation is expected to be much less significant than the loss in ASHP efficiency that the operational strategy seeks to avoid. Furthermore, while this strategy proposes reducing the size of the ground heat exchanger (GHX), the capacity of the heat pumps relying on that source must be sized for the entire peak load and possibly lower entering water temperatures, likely increasing costs for the heat pumps compared to solely providing adequate ground coupling and eliminating the air-source component where possible. Control of hybridized ground-source systems complicates what typically remains a straightforward technology to manage. Results have shown that in many instances, hybrid systems did not function as the designer intended and thus did not achieve the intended result.

The number of applications (five) proposing the use of sewage as a heat source or sink illustrates the growing interest in this resource. Interest in this resource within North America has grown slowly despite widespread large-scale applications in Europe, which include 54 installations averaging 17 megawatts (MW) in capacity (Andrei et al., 2017, p. 5). The characteristics of this heat source have been documented and tested in the U.S. (Phetteplace et al., 1985; Phetteplace and Ueda, 1989). A few installations exist in the U.S., including one large installation currently underway at the National Western Center in Denver, CO (https://nationalwesterncenter.com/about/what-is-the-nwc/sustainability%20regen/energy/). Within the PON 4614 studies, the Syracuse District Energy System study serves as an excellent example of using treated wastewater as a source or sink. This study proposed using treated wastewater from a wastewater treatment plant that processes millions of gallons of water each day. The outfall from that system maintains a year-round temperature of 50°F to 75°F and discharges into a lake (NYSERDA, 2022h, p. 1).

Four installations proposed using surface water or stormwater as a heat source or sink. For heating purposes, using surface or stormwater presents challenges in the climate of New York State. Surface water may approach or reach freezing temperature when the heat source is needed the most. In flowing surface water, temperatures can even drop slightly below freezing, leading to the formation of frazil ice. Frazil ice tends to adhere to solid surfaces (Freitag and McFadden, 1997, p. 402), accumulating on water intakes and/or heat exchanger surfaces, which can block flow channels and inhibit heat transfer.

While water on the load side of a heat exchanger using surface water as a heat source may incorporate antifreeze, extracting heat from surface water will require heat exchangers surfaces to remain below freezing, causing ice accumulation that impedes heat transfer. This issue persists even when surface water temperatures are slightly above freezing.

Stormwater, such as precipitation and meltwater that travels through a storm sewer system, may gain some heat from the ground. However, during periods of high stormwater flow and precipitation at or near freezing temperatures, the impact of this heat gain diminishes. Additionally, winter stormwater typically contains salts from road deicing treatments, which may necessitate special provisions to prevent corrosion, depending on the heat exchanger methods used. Many cases involve stormwater combined with sewage in a single collection system. In these situations, stormwater impacts will be mitigated by the sewage flows; however, during winter months, stormwater impacts may prove detrimental and may overshadow the heat inputs from warmer sewage flows. Thus, the desire to use sewage as a heat source may further justify infrastructure projects aimed at separating stormwater and sewage collection systems, a need traditionally driven by the desire to reduce loads on sewage treatment plants due to stormwater dilution of sewage.

Only one study mentions using heat exchange with groundwater in an open-loop type system, and in that case, it involves an existing but abandoned system on-site. Groundwater-based open-loop systems can prove more cost-effective than ground-coupled systems for larger-scale installations, as expected from the PON 4614 studies. For groundwater-based open-loop systems, cost correlates strongly with system size, with increasing size resulting in lower cost per unit of capacity. Conversely, the cost for ground-coupled systems remains essentially flat; doubling the capacity also doubles the BHX and overall costs. Figure 2 shows the basic relationship between capacity and cost for both groundwater-based open-loop and closed-loop (BHX) systems. The cost data used to create Figure 2 may be outdated, but the relationships are the same. For examples with more current cost data, refer to Figures 8.18–8.20 in Kavanaugh and Rafferty (2014, pp. 315–316). Given these advantages, the lack of interest in groundwater-based open loop systems is surprising. This reluctance likely stems from perceived or actual difficulties in the permitting process. The authors of this report believe that this approach warrants much more attention, aiming to identify potential barriers in the permitting process. As long as stakeholders view this process as too difficult, barriers will remain. Just as the geothermal heat pump industry has succeeded in eliminating the burdensome permitting requirements for BHXs deeper than 500 ft in New York State, unnecessary obstacles to groundwater-based open-loop systems could be removed by industry efforts.

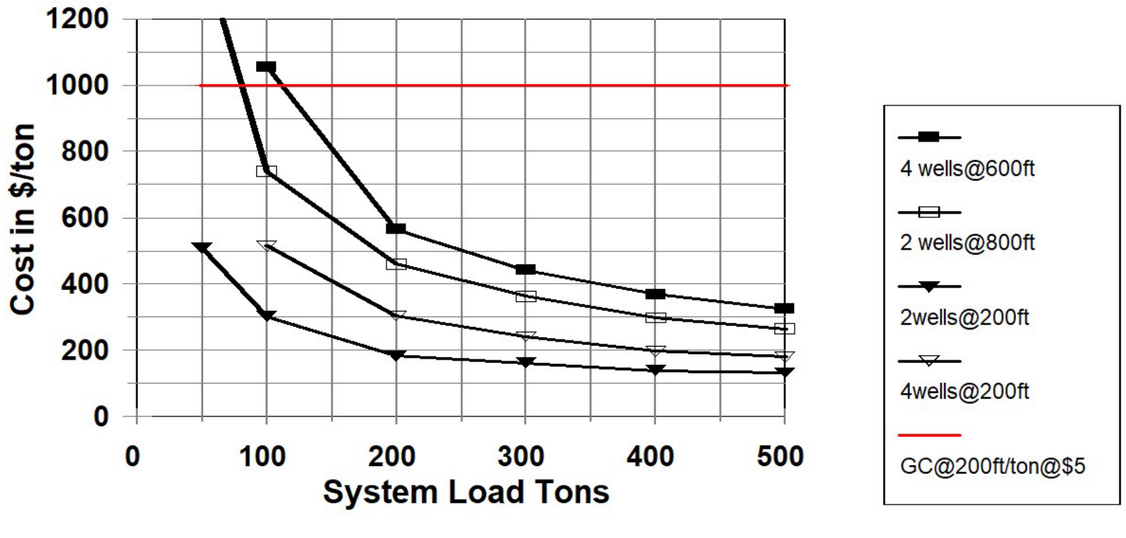
Standing column well-based heat pump systems, as understood, are allowed in New York State. These pose similar groundwater protection issues to open-loop groundwater-based systems. In fact, larger open-loop groundwater-based systems typically incorporate an additional water-to-water heat exchanger to isolate groundwater from the heat pumps. This heat exchanger usually does not exist in standing column well applications. The availability of an adequate groundwater resource is obviously very site specific, but many suitable sites likely exist in New York State. Although standing column wells have experienced issues related to water quality at some sites, additional isolation through a heat exchanger of the groundwater from water that will be used by the thermal energy network can remove most challenges encountered with problematic groundwater chemistries. This isolation also protects the groundwater from contamination.

Finally, groundwater-based systems represent the first commercial application of GSHPs in the U.S., dating back to the early 1950s (Kavanaugh and Rafferty, 2014, p. 263). As groundwater pollution from sources such as leaking underground storage tanks has raised concerns regarding groundwater protection, the industry has shifted toward overly cautious groundwater protection measures. Early battles established the safety of closed-loop BHX systems, and some continue today. In general, however, closed-loop systems have gained widespread acceptance and are seen as a more universal solution, decreasing interest in open-loop groundwater systems. Nevertheless, times have changed, and any risk associated with open-loop groundwater-based systems contaminating groundwater must be weighed against their potential to provide cost-effective carbon reduction alternatives. Much like the renewed interest in nuclear power after four decades, despite minimal risks of accidents and waste storage, open-loop groundwater systems deserve a thorough reevaluation.

Figure 2. Open-Loop Groundwater System Cost versus Ground-Coupled Borehole Heat Exchanger System Costs as a Function of System Capacity

Costs are shown for systems operating with 60°F groundwater

Source: Kevin Rafferty.



Although the studies do not discuss this aspect, a unique opportunity exists for thermal energy network systems where groundwater pollution undergoes remediation through the pump-and-treat process. Pump and treat refers to a method used to remediate contaminated groundwater, where water is pumped from one well, treated to remove contamination, and then returned to another well. Future studies should stipulate the exploration of any local pump-and-treat facilities.

2.2 Distribution Piping System between Buildings

Thermal energy networks function as a type of district energy system, where the cost of the distribution systems and the building interconnections represent a major portion of the capital cost. In the PON 4614 studies, most planned connections between the thermal energy network distribution system and the buildings, as well as the distribution system itself, lacked adequate description and sufficient details. This oversight raises concerns that the importance and cost of the distribution piping system may have been underestimated. For future feasibility and design studies, the following details should be provided as a minimum, in addition to a detailed cost estimate:

- A scale map showing loads and labeling nodes
- Tentative routing of piping overlaid on existing surface features and building maps
- A table by pipe segments between nodes, including segment lengths, flow rates, pipe sizes, and unit costs

Section 3.9 provides a recommended approach for gathering this data.

Table 5 summarizes the information available from the PON 4614 studies regarding the distribution system. Unfortunately, many details useful for characterizing and comparing the studies do not appear in the reports or their attachments.

The proposed distribution systems across the 18 studies varied greatly in the number and size of buildings served, ranging from as few as 3 buildings to a potential of 147. Several educational campuses were included, historically strongholds for traditional district heating (DH), and to a lesser extent in, district cooling (DC) systems in New York State. For roughly a century, district heating using steam or hot water generated by fossil fuel combustion has been the standard for these campus systems. However, the desire to reduce carbon emissions leaves these campuses with limited options for continuing business as usual operation. One transitional technology being used on some campuses in New England involves renewable fuel oils (RFO), either based on recycled cooking oils or cellulosic decomposition. While not entirely carbon-free, RFOs reduce carbon emissions when compared to fossil fuels. Surprisingly, none of the PON 4614 studies that included fossil fuel combustion for peaking or other loads not easily served by heat pumps, proposed using RFOs.

Another option for campuses with existing hot water or steam distribution systems not addressed by any of the PON 4614 studies involves using a portion or all of the distribution system as an ambient temperature loop (ATL). While pipe sizes could present a challenge, this situation is not certain, particularly when converting a steam system to a one-pipe ATL. Steam distribution systems often already include some degree of looping, and the steam pipes typically have larger diameters than those found in hot water systems of the same capacity due to the low density of steam. Also, energy conservation measures implemented since the original design of these systems have likely reduced actual peak loads.

One clear observation from Table 5 shows that the majority of the proposed projects—15 out of 18—included ATLs for all or part of the district to be served. ATLs are an evolving technology that shows great promise for economically extending district heating and cooling into areas of lower load density, which historically have not been served by district energy systems. They are a logical extension of using lower temperatures to serve district heating loads while benefiting from electricity generation through renewable sources with very low carbon loadings. However, ATLs introduce design challenges not seen in other types of district heating and district cooling systems. For example, the studies reviewed did not provide enough detail on piping sizes, such as those shown in Figure 3, to demonstrate the adequacy of the selected pipe sizes.

Table 5 shows that many of the studies (5 out of 18) did not include pipe sizing information, while an even greater portion (15 out of 18) did not include the planned distribution system supply and return temperatures. Both of these parameters, along with the peak loads, which often were given, are needed to calculate pipe sizes.

Table 5. Summary of Distribution System Information

Project[a]	District Extent	Type of Distribution System Outside of Buildings	Distribution System Sizing	Distribution S&R Temps	Distribution System Piping Material	Distribution System Cost $/lf
The Peninsula	3 buildings	2-pipe ATL	6-in mains with 4-in branches to buildings	40 F min.	NP	NP
Silo City	6 historic structures	2-pipe ATL	6 inches	30 F min.	HDPE	NP
Pratt Landing	4 blocks	Options evaluated: decentralized ATL and centralized 4-pipe	Decentralized option, 12-in 2-pipe ATL; centralized option, 4-pipe with 10-in CHW and 8-in insulated hot water	30 F min.	HDPE	NP
Wagner College	6 of 24 buildings	Two systems, each central plant and 2-pipe distribution of heating or cooling water to buildings via seasonal changeover	10-in 2-pipe distribution system from CP to BHX; 8-in insulated heating or chilled water piping to building from CP	30°F min. from BHX	HDPE	NP
Willets Point (Phase 1A)	3 buildings in phase 1A	Decentralized option, 2-pipe ATL; centralized option, 4-pipe heated and chilled water	Decentralized, 12 inches; centralized, 10-in chilled water, 8-in insulated hot water	30° F min. from GeoPiles	HDPE	NP
Innovation Queens	13 buildings	Decentralized, 2-pipe ATL; centralized, 4-pipe for central plant options (+ piping heat source/sink to central plant~~P~~)	NP	30°F min. from BHX option; for sewage source option, supply = 57.1°F, return = 47.4°F	NP	NP
Syracuse District Energy System	34 downtown building with potential for additional 12	2-pipe from central plant to downtown core; downtown area, both 1-pipe and 2-pipe discussed, 2 pipe higher in cost but was used for estimate	For CP to downtown, 2 30- to 36-in pipes at 5-ft depth (min.) below frost line. For downtown distribution 16" in either 1 or 2 pipe.	Leaving plant temps: heating: supply = 80° F, return = 60°F; cooling: supply = 80°F, return = 90°F	HDPE DR11 for CP to downtown, uninsulated	Specific costs for 30-in to 36-in piping from CP to downtown not given; for downtown distribution, 16-in piping, 2-pipe, $1,200/lf; 1-pipe, $900/lf.
Sheridan Hollow	147 potential properties	4 options explored, all ATL, not clear if some options labeled as “hairpin” are 2-pipe ATL	8 in, 10 in, or 12 in, depending on piping configuration option	ATL so same as BHX; 8 alternatives, temps range from 11.7°F–71.4°F to 27.7°F–70.9°F	HDPE SDR-11 (4710 rating for 200 psi)	$2–$2.1M
SUNY Oswego	4 campus buildings	Most likely a hybrid approach; 4-pipe where infrastructure existing (CHW/HW), 2-pipe ATL where heat pumps are installed	Borefield S&R 4 in, 12 in distribution pipe	ATL so same as BHX	Schedule 40 steel pipe (indoor) PE4710 HDPE DR13.5 (subgrade laterals)	$78.00 for 12-in main

Table 5. (continued)

Project[a]	District Extent	Type of Distribution System Outside of Buildings	Distribution System Sizing	Distribution S&R Temps	Distribution System Piping Material	Distribution System Cost ($/lf)
Syracuse University: Community Heat Pump Study	8 buildings	ATL, appears to be 2-pipe	12-in main loop	ATL so same as BHX	PE4710 HDPE DR13.5 (subgrade laterals) Schedule 40 steel pipe (indoor)	$77.42/lf
City of Troy District Energy	21 buildings in phase 1	ATL, not clear if 1- or 2-pipe	NP	ATL, however non-BHX also potentially included	HDPE	$30.50/lf
Children's Village Community	60 buildings	1-pipe ATL	10 in	ATL so same as BHX	HDPE	$3.6M for 12,150 ft = $296/lf
Downtown Utica CHPS	8 buildings	LTHW distribution via insulated piping	4 in and 10 in	140°F supply maximum	Steel	For 10 in: $1,020,000 for 1,700 ft = $600 lf (trench) For 4 in: $360,000 for 1,200 ft = $300 lf (trench)
Buffalo Training Center & residences.	12 buildings, including 11 residences	4 options proposed, 3 of which are 4-pipe district systems	NP	NP	NP	NP
Gowanus Green	6 buildings plus school	2-pipe ATL	NP	ATL so same as BHX	NP	NP
Masonic Care	9 buildings	2 pipe ATL	NP	ATL so same as BHX	NP	NP
Pratt Institute	20 buildings	Various options proposed, many with ATLs	8 in	ATL so same as BHX	HDPE	$279.16/lf
Saranac Lake	Total potential for 70 buildings	2-pipe ATL	16 in–18 in	ATL so same as BHX	DR11 HDPE	$1,325/lf

[a] Eastern Emerald Group, LLC, and Phelps Hospital are omitted from this table because they do not have distribution systems outside of buildings.

Figure 3. Pipe Sizing for Various Water-based District Heating Technologies

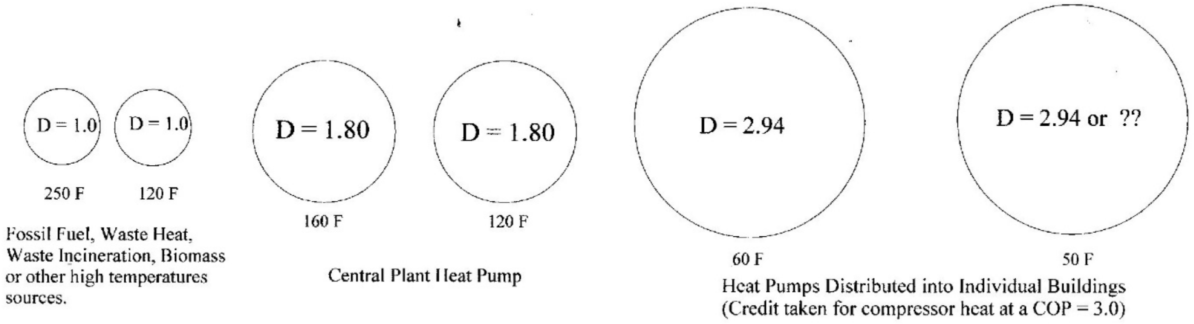


Table 5 indicates that specific costs for buried piping were not provided for 10 of the 18 studies, and where costs were included, they varied significantly. While expected fluctuations in buried piping costs will occur due to factors such as pipe size, soil types, hard surfacing to be removed/restored, piping materials, joining methods, and so forth, some of the costs cited appeared unrealistically low. As a major cost for any district system, underestimating the cost of the distribution system undermines the credibility of a feasibility study.

Most studies proposing ATL systems, with the Saranac Lake study as an exception, assume that heat losses and gains from the horizontal distribution piping are beneficial, are negligible, or at least do not degrade performance. The authors of the Sheridan Hollow study state, “Simulations do not account for any heat transfer from the horizontal piping which has been observed as helping modulate thermal performance in networked geothermal systems” (NYSERDA, 2023d, p. 70). While this may be true in more temperate climates, it does not always apply to colder climates, such as those in New York State. Furthermore, the coincidence of seasonal minimum and maximum soil temperatures with minimum and maximum ground-coupling temperatures may aggravate the problem.

New York State has varied climates. For example, the mean annual air temperature at the Adirondack Regional Airport (near Saranac Lake in the northern part of the State) is 40.2°F (TC 6.2, 2019), while at LaGuardia Airport (in the southern part of the State), the mean annual air temperature is 56.1°F (TC 6.2, 2019). Although these temperatures may represent extremes for the State, they illustrate the wide variation in climate.

A proposed PON 4614 project in Saranac Lake, near the Adirondack Regional Airport, prompts an examination of how this climate impacts the soil temperatures surrounding the buried distribution piping system. Figure 4 shows the predicted subsurface soil temperatures derived from climatic data provided by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) TC 6.2 (2019), using the calculation Phetteplace et al. (2019, p. 4.26–4.29) outlined. Each sinusoidal curve in Figure 4 represents a depth below the ground's surface.

Two impacts are obvious when examining Figure 4. First, the temperature variations are "dampened" for the deeper burial depths. Second, also from the dampening effect of increasing soil depth, are the times during the year when the minimum and maximum soil temperatures occur. For example, at a depth of 6 in, the minimum annual temperature occurs about January 20, or Julian Day 20, as shown in Figure 4, which aligns with expectations. However, for the maximum of the depths shown, 24 ft, the minimum temperature does not occur until approximately Julian Day 165, or mid-June. While few thermal energy networks will bury horizontal distribution piping 24 ft deep, the impacts remain significant at moderate depths of 3–6 ft, where most horizontal distribution piping of thermal energy networks will likely be buried. In this 3- to 6-ft depth range, minimum temperatures occur from mid-February to early April, and these minimums will be significantly lower than those at greater depths shown in Figure 4.

For a community heat pump system relying solely on BHX, the most popular heat source or sink in the PON 4614 studies, annual temperature fluctuations will also occur. The nature of these variations depends on the BHX sizing and design, building loads, and undisturbed ground temperatures. In an ATL system, temperatures within the distribution system piping will vary similarly to those in the BHX. For systems without antifreeze, the lowest temperature will reach approximately 38°F and will occur significantly later in the winter, after the peak heating load, around the end of March. The maximum temperature that the BHX and its ATL system will experience again depends on the BHX sizing, design, and nature of the building loads. For a heavily heating-dominated climate, with BHX designed for a minimum of 38°F, the maximum temperature might approach 75°F.

Figure 5 summarizes the soil temperatures and expected BHX temperatures over the annual cycle. As Figure 5 illustrates, at a burial depth of 3–6 ft, the estimated BHX temperature consistently exceeds the ground temperatures at these depths. This means that the distribution piping of an ATL system relying on BHX will continually lose heat. System designers must compensate for this heat loss by increasing BHX capacity or insulating distribution system piping. Generally, proponents of ATL systems largely ignore this factor. While this assumption may be valid in some cases, it does not universally apply. In heating-dominated climates, for systems without antifreeze, the impact becomes especially pronounced as demonstrated by Figure 5.

Figure 4. Estimated Annual Subsurface Soil for the Adirondack Regional Airport Climate Data

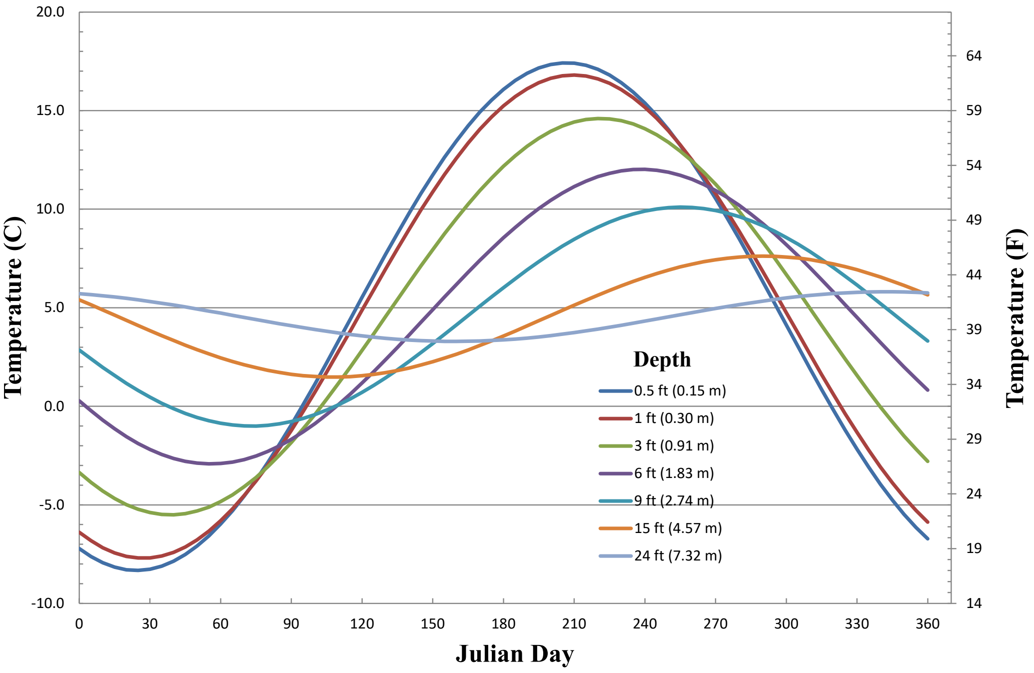


Figure 5. Annual Ground Temperature in the 3- to 6-foot Burial Range for the Adirondack Regional Airport Climate Data Compared to Borehole Heat Exchanger Temperatures

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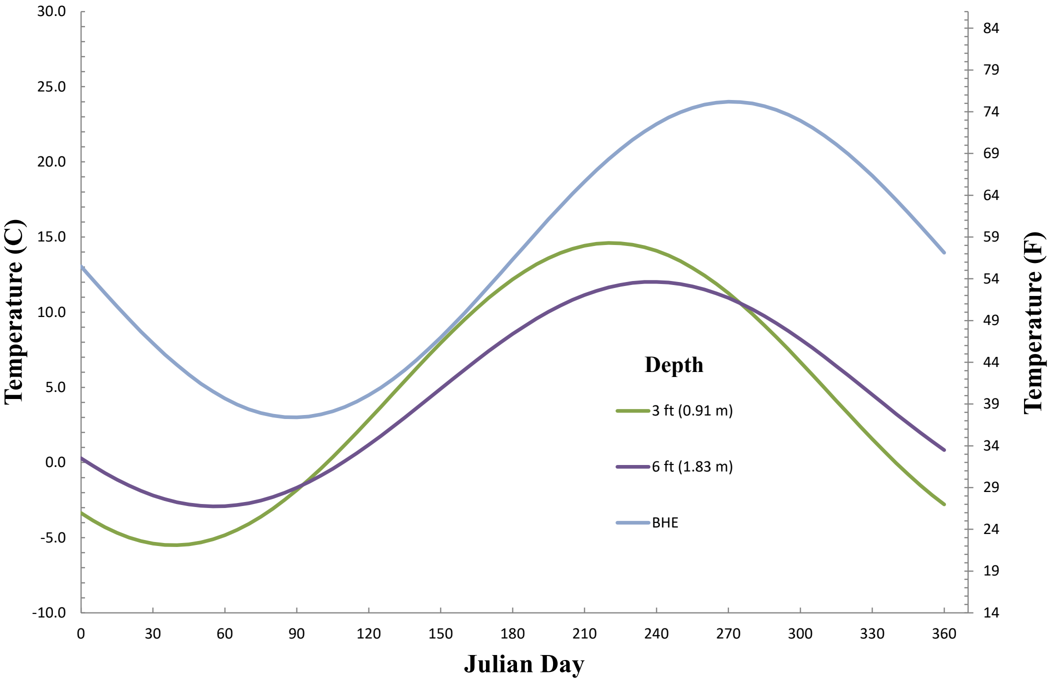

Estimating soil temperatures using climatic data and soil properties is straightforward and requires consideration in geothermal heat pump design, as commonly done for BHX based on in situ soil thermal conductivity tests. Thermal energy networks must account for the contributions and impacts of the horizontal portions of piping. Given the ease of estimating soil temperatures for any climate and depth, misrepresentations or overly generalized statements regarding soil temperatures must not be spread.

2.3 Definition of a Thermal Energy Network, Reviewed

The minimum project eligibility requirements for PON 4614 included project sites with at least two buildings and a minimum of 40,000 sf of conditioned space. The requirements were developed in consultation with stakeholders to provide visibility into potential opportunities in New York State.

Discussions with NYSERDA and solution providers demonstrated the need for common terminology and definitions that align more closely with industry standards and ongoing market developments in New York State, including the Utility Thermal Energy Networks and Jobs Act.

Several projects explored options that included both thermal energy networks, as defined earlier, and dedicated GHX systems for individual buildings within a single ownership structure. This approach aims to reduce installation, maintenance, and operational costs. Both approaches use the same formation or local geology, although they use different piping configurations. Additionally, the alternative of a dedicated GHX for each building could later be integrated into a thermal energy network. This integration might offer cost advantages if new buildings with differing load profiles join the existing group.

The feasibility studies reviewed ranged in total square footage from 163,568 sf at SUNY Oswego to 3,121,977 sf at Innovation Queens. The recommended minimum project size for qualifying geothermal projects for NYSERDA-matched funding is 150,000 sf, regardless of building type.

2.4 Life-Cycle Cost Analysis

LCCA represents the total cost of owning, operating, maintaining, and disposing of systems over a specified study period, typically aligned with the project’s lifespan. All costs are adjusted to reflect the time value of money through discounting (Kneifel and Webb, 2022, p. 3).

LCCAs were provided for all feasibility studies comparing baseline or business-as-usual options with all-electric or mostly-electric alternatives. The proposed options demonstrate greater energy efficiency than the baseline option and reduced carbon emissions. Some studies also examined payback periods, which often appeared unfavorable. The payback method focuses on the time required to recover the initial investment, making it an inadequate measure of long-term economic performance or profitability. The payback method ignores costs and savings that occur after reaching the payback point and fails to differentiate between project alternatives with various useful lives, often using an arbitrary payback threshold. Moreover, the simple payback method, commonly used, ignores the time value of money when comparing future savings with initial investment cost (Kneifel and Webb, 2022, pp. 82–83).

An example from the SUNY Oswego Feasibility Study illustrates this point. The explanation following the Summary of Costs in the Economic Analysis states that, “Compared to the existing system and maintaining the status quo, the geothermal wellfield does not provide simple payback due to the relatively high cost of electricity. Therefore, it does not make sense to install the system based on economic reasons alone. However, to achieve net-zero in the future; as is the goal for SUNY Oswego, an electrified heating solution is imperative” (NYSERDA, 2023a). While simple payback appears unfavorable for both the individual building heat pumps and community heat pump options, these systems are more energy efficient and result in a 50% to 52% reduction in carbon emissions compared to the baseline system that includes steam from a central plant produced using natural gas boilers.

Each solution provider consistently selected LCCA variables, such as duration, interest rates, inflation rates, and so forth; however, comparing studies side by side is challenging due to variations in these selections. To simplify future LCCA reviews, NYSERDA should standardize and provide annual rates based on NIST recommendations. See “Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis” in the Annual Supplement to NIST Handbook 135 (Kneifel and Webb, 2022, p. 1).

Significant time goes into estimating installation or capital costs and the annual operation and maintenance costs of project options. Accurately estimating costs requires preliminary design efforts to assign values to each system option and estimate system efficiency for determining operating costs. Some providers used costs from previous projects or figures provided by equipment vendors. In some cases, insufficient detail hindered the ability to determine whether the distribution system costs received were sufficiently estimated. Typically, distribution piping costs for a district energy system can account for 30% or more of the total capital investment. Recommendations for improving distribution cost estimates in future feasibility studies appear in Section 2.2, and Section 2.9 provides additional detail.

Maintenance costs varied widely, as shown in Table 6. This variability is not surprising given the diverse approaches and project ownership structures. For projects on existing campuses, such as Wagner College or Syracuse University, historical maintenance cost data exists due to on-site maintenance staff. In contrast, new building projects considered for inclusion in a new thermal energy network used different sources for determining maintenance costs. Some providers cited maintenance costs provided by equipment manufacturers but failed to offer references.

Table 6. Summary of Thermal Energy Network System Maintenance Costs from Program Opportunity Notice 4614 Feasibility Studies

Project	Location	Building Type	HVAC System	Annual Cost	$/sf
Eastern Emerald Group	Queens	Tower, mixed-use	GSHP + ASHP	$112,526	—
Eastern Emerald Group	Queens	Commercial	VRF	$10,305	$0.15
Eastern Emerald Group	Queens	Hotel	GSHP	$102,221	$0.25
Peninsula	Bronx	Multifamily	VRF/ASHP + GSHP	$9,793	$0.02
Silo City	Buffalo	Adaptive reuse, apartments, mixed-use	VRF/ASHP + GSHP	$112,446	$0.20
Pratt Landing	New Rochelle	Retail, residential, conference, and performing arts	VRF/ASHP + GSHP	$48,000	$0.06
Wagner College	Staten Island	College campus	GSHP + ASHP	$70,000[a]	$0.18
Willets Point Phase 1A	Queens	Residential and school	Decentralized GSHP	$48,000	$0.04
Innovation Queens	Queens	Affordable housing, commercial businesses, arts culture hub, and health and wellness facility	SHX	$159,000	$0.05
			Decentralized GSHP	$217,000	$0.07
Syracuse District Energy System	Onondaga Lake	Urban core including existing DH & DC system[b]	Central plant, cost is for part-time operator and plant maintenance activities only	$120,000	$0.06
Sheridan Hollow	Albany	Residential neighborhood	Decentralized GSHP	50,000	$0.11
SUNY Oswego	Oswego	College campus	District GSHP	$15,316	$0.09
			Buildings with dedicated GHX	$15,716	$0.10

Table 6. (continued)

Project	Location	Building Type	HVAC System	Annual Cost	$/sf
Syracuse University	Syracuse	Mixed-use, multibuilding, including data center	District GSHP	$58,127	$0.19[c]
			Buildings with dedicated GHX	$57,679	$0.19[d]
City of Troy District Energy System	Troy	Mixed-use, residential, office, education, retail	ATL (3 phases)	$51,000	$0.04
Children's Village Community	Dobbs Ferry	Mixed-use, residential, education, recreation, administration	ATL, 1-pipe	$442,500	$0.99[e]
City of Utica	Utica	Mixed-use of 8 existing buildings	Central plant HW system with GSHP/electric boiler plant	$998,000	[f]
Gowanus Green	Brooklyn	Mixed-use of 6 buildings, residential, retail, (school not in contract)	Centralized plan with energy piles, GSHP and ASHP	$67,900	$0.07
Masonic Care	New Rochelle	Former educational campus	Centralized GSHP with supplemental NG heat and supplemental electric cooling		$0.31 [g]
Pratt Institute	Brooklyn	Educational campus	Campus system integrating open well loop, GSHP and ASHP		$0.05/ton-hr of chiller operation and $0.10/ton-hr for heat pump operation
Saranac Lake	Saranac Lake	Small village, mixed-use, 70 possible buildings	District GSHP and lake cost is for part-time operator and plant maintenance activities only	$100,000	

[a] For comparison, the operation and maintenance (O&M) costs for the existing central energy plant is listed as $1,955,00 for Wagner College. See table 9 of that report for more details (NYSERDA, 2022c).

[b] Maintenance costs for the existing Syracuse District Energy System cited $651,000 annual cost for cooling tower O&M, including Legionella testing, service calls, water, and chemical use (NYSERDA, 2022h).

[c] Maintenance cost based on testing and service from vendor estimates.

[d] In-house maintenance costs.

[e] In-house maintenance costs (Wu, 2007, pp. 31–32).

[f] The total cost is for O&M; maintenance was not broken out separately.

[g] Blended rate per square foot for O&M.

No maintenance cost data was provided for the Buffalo Training Center or Phelps Hospital. In the LCCA for the City of Utica, an operation and maintenance cost of $998,000 appears after the first year of installation for the thermal energy network, but no other details were included. For Sheridan Hollow, the maintenance costs were taken from Table 17 (NYSERDA, 2023d) and divided by the total heating square footage the project. Although somewhat dated, chapter 38 of the *2023 ASHRAE HVAC Applications Handbook* offers several sources of maintenance data (ASHRAE, 2023b, p. 38.7). When historical data is unavailable, the best current information typically comes from companies that provide contracted maintenance services.

2.5 Carbon Dioxide Emissions Reduction

Feasibility studies provided information on carbon dioxide (CO_2) emissions reduction for alternative mechanical and heating hot water systems (when applicable) compared to business-as-usual systems. The inconsistent presentation of this information complicated reviewers' ability to determine which projects would provide the greatest reduction in greenhouse gas emissions. Some studies provided percentage reductions in CO_2 emissions, others reported reductions in CO_2 emissions or CO_2 avoided as an annual value, and others provided the total CO_2 reduction for the total duration of the feasibility study.

Future reviewers must also consider the age of the building stock when comparing projects for CO_2 emissions reduction. Many projects already planned for construction were designed to be primarily electric. In these cases, the savings from converting an ASHP system to a geothermal heat pump system were smaller than the savings from converting gas-fueled boilers to heat pumps.

Local Law 97 (LL97), implemented by the New York City Department of Buildings, imposes a fine for exceeding a building emissions limit beginning in 2024. The fine is $268 for each metric ton of carbon dioxide emissions above a building's established limit. Feasibility studies for New York City projects captured this information.

For studies proposed outside of New York City, solution providers referenced guide and policy documents provided by the NYS Department of Environmental Conservation (DEC), which lists the social cost of carbon as $125 per metric ton of CO_2. Although all alternatives proposed to business-as-usual options showed a reduction in CO_2 emissions, solution providers did not use this social cost of carbon as a disincentive or credit in the LCCA.

Many feasibility studies showed that without matched funding from NYSERDA and carbon taxes, community heat pump projects remained unattractive to developers. While NYSERDA initiated the possible application of community heat pump systems in New York State, it cannot sustain this level of investment indefinitely. Ratepayers currently fund these projects, so future funding must come from both private and public entities. Evaluating thermal energy networks long-term investment, coupled with implementing carbon taxes, may incentivize these substantial and capital-intensive projects.

During solution provider interviews, one provider stated, “The CO_2 tax has to be significant enough to make a difference. We do account for New York City Local Law 97 in our LCCA. So far, it has been a rounding error [not a significant impact].” While this comment may apply to projects already planning to use all-electric heating, ventilation, and air conditioning (HVAC) and domestic hot water heating systems, a second review of the CO_2 calculations for different projects and solution providers revealed a contradiction.

The Syracuse District Energy System, referenced in (NYSERDA, 2022j) is located outside of New York City. The feasibility study provided information for calculating CO_2 emissions, including data for both kilowatt hours (kWh) and million British thermal units (MMBtu), along with the total annual CO_2 tax penalty based on \$125 per metric ton of CO_2e. “Indirect benefits of the system include the social cost of the carbon emissions avoided during the 25-year study period as defined by the NYS Department of Environmental Conservation (DEC). A net present value (NPV) of \$8.8M in avoided carbon emissions was calculated; however, under current law and market conditions there is not an available avenue to monetize this value for the benefit of the project” (NYSERDA, 2022j).

This report recommends that annual CO_2 emission reductions be reported for each proposed project option to facilitate comparisons among projects. Projects impacted by New York City Local Law 97 should include avoided penalties in the LCCA. Projects outside of New York City should apply the carbon value according to guidance from NYS Department of Environmental Conservation and show life-cycle costs both with and without this value included.

2.6 System Efficiency

When a manufacturer presents heat pump equipment efficiency data in its literature, the documentation typically follows a standard rating test procedure. The energy efficiency of that equipment is given for fixed test condition. To define the energy efficiency for actual operation accurately, one must adjust the COP or energy efficiency ratio (EER) to the design conditions for heating, cooling and/or domestic hot water heating systems. Most manufacturers provide tables that include varying entering water temperatures, flow rates, capacities, COP, EER, and examples of how to adjust this data to the required design temperature and flow rates.

All the equipment in a thermal energy network, including pumps, heat pumps, chillers, fans, and cooling towers, should be identified, and a system efficiency calculation should occur based on the total weighted value of the system operating in cooling and heating modes. Relying solely on the heat pump manufacturer's rated equipment efficiency as a basis for operational data usually leads to inaccuracies. This approach fails to tell the full energy story because the pump and fan energy required to distribute or remove heat from a building is not captured in a single component efficiency value. Generally, unitary equipment serving zones directly offers much higher system efficiency than approaches using large central chillers or heat pumps that provide heating and cooling through ducted air.

The Excel worksheet templates NYSERDA provided to solution providers performing PON 4614 studies require an itemized listing of heat pump equipment, including COPs and EERs at design temperatures for each heat pump. While this information helps account for all specified equipment, calculating overall system efficiency at design or averaged design conditions remains essential. Reports must clearly state how the efficiency values are determined and accounted for to estimate annual energy consumption and the resulting operational costs. Section 3.3 includes recommendations for calculating system efficiency.

Although solution providers demonstrated increased energy efficiency for alternatives to business-as-usual systems in their feasibility studies, they often resulted in increased operating costs when switching from natural gas to electricity. The lower cost of natural gas in many locations is often the main barrier to accepting all-electric alternatives, even with carbon tax penalties. The economic analysis provided in Table 41 of the "Syracuse University: Community Heat Pump Study," which compares a GSHP system to the option of replacing the existing system in kind and shows that a reasonable payback is not possible. The report notes, "Although the costs of proposed options are high, the carbon emission reductions with the community heat pump system is remarkable—saving almost 50% of the entire cluster's emissions" (NYSERDA, 2022ki, p. 64). This high percentage of emission reductions is attributed to the high efficiency of the electric heat pumps and the elimination of natural gas on-site. As one solution provider mentioned during interviews, the most significant barrier to electrification is the operating cost component for new construction; electricity costs are high while gas remains cheap.

2.7 Resiliency

The statement of work in PON 4614 required solution providers to address resiliency. During interviews, solution providers emphasized that thermal energy networks should receive consideration similar to that of any other utility. While this is a valid point, one must examine not only the effects of electric-power outage, but also those impacts on the district energy system and each building's connections due to natural hazards, climate change-related extreme weather, and the recovery time of the system after such events.

District energy systems that use central plants instead of decentralized equipment demonstrate proven resiliency against electric grid failures caused by extreme weather events. This reliability is well-documented; for example, the International District Energy Association (IDEA) reports that district cooling systems have a reliability of 99.94% (IDEA, 2008, p. 2). Providing a backup generator for a single central plant generating heating hot water and chilled water distributed to a community through a district energy system proves much easier and less costly than ensuring adequate backup generation for electric-driven heat pumps distributed to the building. District energy plants maintain backup equipment in a ready state, a situation seldom found in individual building systems, except in critical infrastructure. Additionally, a district energy central plant can easily be configured to use a second fuel during emergencies.

These features contribute to the resiliency and reliability of central plant-based district energy systems. Recent extreme weather events have reinforced this resiliency. For example, during Hurricane Sandy and its aftermath, district energy systems with co-generation kept the heat and lights operational at Princeton University (Jones, 2019, p. 68–69). Similar experiences occurred at the University of Texas at Austin during the great Texas freeze in February 2021 and during an unprecedented heat wave in June 2021 in the Pacific Northwest, which the University of British Columbia managed using its district cooling system (Israelsen, 2023, p. 33–35).

Assuming stakeholders treat thermal energy networks as utilities, this discussion focuses on the resiliency of the thermal energy network up to the energy transfer station (ETS) at each building. As discussed with solution providers during interviews, each building owner must determine their own level of risk for equipment on the consumer side of the energy transfer station. When the thermal energy network system owner also owns the building equipment, the point of demarcation shifts and requires further consideration.

Among the 20 feasibility studies, only 5 did not specifically address resiliency. Of the remaining 15 feasibility studies, only 6 included dedicated sections on this topic, while 2 reports remained in draft format and lacked content on resiliency.

Solution providers identified several strategies to enable central plants and/or pumping stations to operate independently of the electric grid.

- Battery storage: This option can be incorporated into the photovoltaic (PV) system, operates the system during peak demand, and serves as backup energy during outages.
- Engine-driven backup generator: This option provides emergency power during events to maintain minimal system functionality. Noncritical buildings may operate through temporary derating of their equipment.

For thermal energy networks, several solution providers noted that N + 1 redundancy of equipment, such as pumps, allows the system to operate at full capacity during failures or required maintenance. However, providing this redundancy for a distributed system might be more costly to the owner if a decentralized heat pump system were selected. One argument proposed that using a hybrid ASHP + GSHP system with a GHX design sized for a portion of the total annual heating or cooling load inherently provides both flexibility and resiliency.

In the case of the "Heat Pump System Scoping Study: The Children's Village Community," the report noted the benefits of the phased construction approach that keeps children away from the construction areas over several years. They noted, "Smaller circuits inside the communal loop also add resiliency to the system by providing the option to section off portions of the system to maintain service in some buildings, while repairs are being made in another area" (NYSERDA, 2022e, p. 13).

Only one solution provider, Masonic Care New Rochelle study, addressed the electrical power aspect of the thermal energy network. This provider recommended designing switchgear with additional redundancy and resiliency to ensure critical loads remain operational in case of a bus failure. The switchgear would use Schweitzer Engineering Laboratories (SEL) relays and fused switches to ensure safety and protection of the equipment throughout its lifespan (NYSERDA, 2022a, p. 49).

Resiliency remains a topic of interest for ASHRAE's Technical Committee (TC) 2.10, which oversees a handbook chapter on the topic (ASHRAE, 2023, p. 61). While this chapter primarily addresses HVAC security against chemical, biological, radiological, and explosive threats, it contains much information for surviving extreme climatic events, with anticipated growth in future revisions. Additionally, two other ASHRAE documents focus on resilient design for cold climates, under which New York State qualifies. ASHRAE (2021) specifically addresses thermal systems, including district heating, while ASHRAE (2022) serves as a design guide for buildings in cold climates, incorporating resilience, sustainability, and renewable energy.

Each proposed project option should clearly demonstrate the system's ability to operate during electric grid outages and meet individual design criteria to ensure the system can withstand changing climate conditions and extreme events over its useful life. Similar to other utilities, intentionally designing for anticipated climate conditions—such as installing critical equipment above the future floodplain elevations, sizing the system for higher average temperatures, and protecting backup power—will increase reliability and performance.

2.7.1 Impact on the Grid

Most providers assessed the impact on the electric power grid resulting from the proposed utility demands of their projects. Table 2 summarizes the expected impacts on the grid for these projects. Many of the proposals involved transitioning from natural gas or fuel oil to electricity as the primary energy source, which would increase loads on the grid. Only six of the projects anticipated reducing impacts on the grid; one of these required behind-the-meter solar photovoltaic to achieve reductions, while another expected reductions only when in comparison to converting all buildings to electric boilers or heaters.

Many studies indicated that aggregating loads into a district scheme, rather than relying on standalone building electrification, would reduce overall demand on the grid. The extent of these reductions depended on the diversity of the loads temporally as well as the existence of simultaneous heating and cooling demands.

2.7.2 Electric Vehicle Charging Stations

Many projects proposed adding electric vehicle charging stations; however, the requirement in the PON 4614 is not directly related to the thermal energy network systems that this report focuses on.

2.8 Disadvantaged Communities

Consistent with Climate Act goals, PON 4614 strives to maximize benefits for disadvantaged communities (DACs). The definition of disadvantaged communities includes projects physically located in these areas and in low- to moderate-income (LMI) housing. Therefore, PON 4614 seeks to develop a pipeline of thermal energy network projects that are either physically located in disadvantaged communities or serve LMI housing.

As shown in Table 1, among the 20 sites analyzed in this report, 9 (45%) were located in disadvantaged communities and had the following characteristics:

- Approximately 9M sf of conditioned space across 250 buildings
- Two new construction or gut rehabilitation projects; seven existing buildings or a mix of existing and new structures
- All but two projects included residential space

Developing a pipeline of thermal energy networks serving LMI housing also served as a goal of PON 4614. The inclusion of LMI multifamily (MF) housing was part of the proposal evaluation criteria for PON 4614.

The most recent revision to PON 4614 Category C included the following evaluation criteria related to LMI housing:

- How many LMI individuals and affordable housing buildings will benefit from the project? Did the proposal include documentation from the U.S. Department of Housing and Urban Development, the New York City Department of Housing Preservation and Development, or other agency, such as a copy of an award letter, to demonstrate that the housing qualifies as affordable housing?
- To what extent does the project provide considerations and/or include workforce development opportunities for LMI residents, minority- and women-owned businesses, service-disabled veteran-owned businesses, formerly incarcerated persons, and/or other priority populations as defined by NYSERDA (N.d.)?
- Are any LMI tenant associations, minority- and women-owned businesses, service-disabled veteran-owned businesses, formerly incarcerated persons, and/or Climate Justice advocacy organizations participating on the project team?
- What are the impacts on and benefits to communities that include LMI residents and/or affordable housing?

NYSERDA typically defines LMI MF housing as buildings where 25% or more of the tenants have incomes at or below 80% of the area median income. Among the 20 feasibility studies reviewed, fewer than half included potential LMI MF housing. A few projects discussed LMI MF, but the feasibility studies did not clarify whether the project sites included housing that met the criteria for LMI MF status. Additional documentation will be required from projects for NYSERDA to verify that housing is LMI MF. Some projects indicated the possibility of nearby LMI MF housing or future phases of project development including such housing.

As the pipeline of thermal energy network projects serving LMI housing develops, the following recommendations should be considered:

- NYSERDA should work closely with staff from the NYS Department of Public Service staff on the Utility Thermal Energy Networks and Jobs Act Public Service Commission proceeding (DPS, n.d.) to address the requirements for Customer Engagement and Protection Plans.
- NYSERDA should consider cross-cutting issues affecting electrification of LMI housing, including:
  - Strategies to maximize benefits for LMI tenants
  - Approaches to leverage electrification to reduce energy burdens for LMI tenants
  - Strategies to minimize or eliminate the cost shifting of heating and cooling expenses from landlords to LMI tenants

2.9 Multifamily Housing

The requirement that landlords provide both heating and domestic hot water as part of the monthly rent for each residential unit reduces building developers’ interest in investing in thermal energy networks due to the added costs of providing a centralized system. The following concerns challenge the implementation of thermal energy networks for MF housing projects.

- Building owners may resist hiring full-time staff to manage the central plant and piping system. This challenge depends on the design of the existing system and the planned ownership structure of the thermal energy network. If the building owner currently employs someone to manage a central heating and hot water system, transitioning to third-party ownership or operation of the thermal energy network could mitigate this concern.
- Adding space above the ceiling on each floor for distributed heat pumps increases the cost of the building envelope.
- Increasing project costs for providing structural support for a central plant on the roof poses a financial burden.
- Running distribution piping throughout a building can create maintenance challenges over time. Should a problem arise, it could disrupt heating or domestic hot water services for tenants. This issue applies to both central plant and distributed geothermal heat pump systems.

- Occupying rentable floor space with central plant equipment is not appealing to building owners. Whether this presents a significant challenge, however, is highly dependent on the design of the existing heating and cooling systems and thermal energy networks. In many cases, implementing such systems could lead to an increase in rentable floor space compared to existing systems.

As the risk of negative health impacts from extreme heat increases, providing affordable and reliable cooling to tenants—especially those in vulnerable populations—becomes increasingly important. However, landlords are not currently required to provide cooling to tenants, which creates a barrier to investing in thermal energy networks. The standard HVAC design typically involves dedicated equipment for each tenant, if any, and usually at the tenant's expense.

One lesson learned from the Peninsula study regarding MF housing highlights the business-as-usual approach: "The choice to move to a system that reduced source energy by 46% and achieved 32%–34% carbon savings was penalized an additional 10% utility cost. This is particularly germane in the [MF] housing sector, where the building owner is responsible for all heating and [domestic hot water] production costs [and passes those costs along to tenants] and is therefore particularly sensitive to operating costs on those line items" (NYSERDA, 2022c, p. 46).

2.10 Regulatory Considerations

The 20 PON 4614 studies generally summarize local, State, and federal permitting requirements, such as the State Environmental Quality Review Act, the National Environmental Policy Act, the Rivers and Harbors Act, and the Endangered Species Act. Most of the studies sufficiently covered the regulatory issues associated with their proposed projects. However, several studies provided thorough summaries of regulatory considerations for specific project locations. Future providers should refer to the following information based on the location and features of the selected thermal energy network.

Willets Point (NYSERDA, 2022l): Appendix D of this report offers a comprehensive overview of regulatory information relevant to a project located in New York City. This project sits in a flood plain, is designated as a brownfield site, and proposes construction close to the water, which means the water table is relatively close to the surface. The report provides an overview of federal laws and regulations including the Clean Water Act, the Rivers and Harbors Act, the National Environmental Policy Act, the National Historic Preservation Act, the Endangered Species Act, and the Safe Drinking Water Act.

At the State level, the document discusses the State Clean Water Requirements, the application of State Discharge and General Water Quality Standards Application to geothermal projects, the State Pollutant Discharge Elimination System, which controls wastewater discharge, the Protection of Waters Permit, and Tidal Wetland Permit. The report also addresses Lands Now or Formerly Under Water and its implications for geothermal project permitting, as well as the State Environmental Quality Review Act, which considers many of the aforementioned topics, including endangered species. Finally, the report includes information about the New York City Local Waterfront Revitalization Program, which consolidates 56 New York City and State policies into 10 categories.

Innovation Queens (NYSERDA, 2022f): This report serves as a source of regulatory information for projects considering the use of a sewer heat exchanger as part of the thermal energy network. Appendix C includes regulatory considerations listed earlier and discusses utilities regulation, specifically determining whether a certain activity qualifies as a utility service. This discussion pertains to identifying a thermal energy network as a utility.

In New York City, the Department of Environmental Protection administers sewer regulations. Starting on page C-21, the report addresses several considerations for this type of heat source or sink, including right of way, sewer connection permitting, temperature of discharge, and system construction.

Silo City (NYSERDA, 2022h): This report includes a regulatory study for both a retrofit project and the Buffalo, NY, location. The project sits in a wetlands area that serves as a habitat for endangered species. This location also falls within a Seismic Site Class D, which imposes additional regulatory and code requirements for the building foundation and structure.

Proximity to the Buffalo River gives the U.S. Army Corp of Engineers jurisdiction to approve any development that impacts water and environmental permits. Silo City is on the edge of an “area of concern” due to industrial pollution, invoking many of the federal and State regulations referenced in the Willets Point report.

One of the Silo City buildings appears on the National Registry of Historic Places, and two others are eligible for listing, which introduces additional challenges for project permitting.

3 Recommendations

3.1 Standardize Life-Cycle Cost Analysis Inputs

For thermal energy networks, an LCCA provides a reliable method of determining economic feasibility. The LCCA directly contrasts with the payback method of economic analysis discussed previously. The NIST Handbook 135 (Kneifel and Webb, 2022) serves as a recommended guide. While this guide focuses on federal buildings and facilities, its terminology aligns with the ASTM International (ASTM) E833-14 (2021) and other standards governed by ASTM Committee E06 on Performance of Buildings, specifically Subcommittee E06.81 on Building Economics.

The latest update to Handbook 135, published in 2022, includes an annual supplement (Kneifel and Lavappa, 2023) titled "Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis" (Kneifel and Webb, 2022).

To ensure consistency across project feasibility studies, include the following minimum elements:

- Define a study period of 40 years, or establish the period based on the client's perspective. This period may differ for outside investors, public infrastructure, universities, government, LMI MF housing, depending on private versus public funding.
- Provide minimum inputs for the LCCA, including the discount rate (or investor's minimum acceptable rate of return), general inflation, inflation rate for natural gas or other fuels, and inflation rate for electricity. From this set of input data and assumptions, calculate an adjusted internal rate of return.
- Use realistic equipment lifetimes, as outlined in New York State Joint Utilities (2023) and ASHRAE (2023, chap 38)
- Conduct a sensitivity analysis of the project that examines different escalation rates, inflation rates, and study periods.
- Include the cost of water.
- Incorporate the annual cost of carbon as a credit to the project cost, where applicable.
- Apply an estimated residual value[1] of a distribution system and sources or sinks, as applicable, at the end of the project study period.
- Report the system COP and EER.

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[1] The residual value factor is the percent of the initial replacement cost in base-year dollars remaining at the end of the study period (or at the end of the expected life of the replacement, whichever is sooner). A negative rate can be entered if the residual value is a disposal cost. BLCC5 uses the average annual rate of increase specified for the replacement cost along with this factor to compute the actual residual value in dollars. Two studies that did not have distribution systems outside of buildings are omitted from Table 4: Eastern Emerald Group, LLC, and Phelps Hospital.

For greater uniformity in LCCA reporting, obtain the general inflation rate, the inflation rate for gas or other fuels, and the inflation rate for electricity from NYSERDA. Table 7 gives a comparison of values used in four reports by different solution providers.

Table 7. Comparison of Reported Variables for Life-Cycle Cost Analysis

	The Peninsula	Children's Village Community	Syracuse District Energy System	Syracuse University
NYSERDA report no.	22-17	22-29	25-03	22-36
Discount rate	4%	5%	7%	7.25%
Inflation rate	2.5%	2.5%	–	–
Inflation for gas	3%	1.5%	5%	6.6%
Inflation of electricity	3%	1.5%	5%	4.1%

For providers who do not have an LCCA template, worksheet, or tool in place, NIST offers a free software tool, Building Life-Cycle Cost (BLCC). Users can download this tool from the NIST website (https://www.nist.gov/services-resources/software/building-life-cycle-cost-programs). To access the tool, ensure that Java 1.8 or a more current version is installed on the computer.

This recommendation does not prevent the solution provider from assessing economic feasibility from other perspectives; however, conducting an LCCA remains essential, and relying solely on a simple payback calculation is not advisable (see explanation in Section 2.4). From the LCCA, users can also calculate net savings, savings-to-investment ratio, adjusted internal rate of return, and years to payback.

3.2 Address Building Efficiency

For thermal energy networks, understanding the impact of connected building envelopes on operating and capital costs, especially the cost of the GHX, proves crucial. The NYS Commercial Energy Conversation Construction Code incorporates both the International Code Council Energy Code and ASHRAE Standard 90.1, ensuring that both new and retrofit construction projects meet minimum energy efficiency levels. While improving the building envelope reduces the energy required for heating and cooling, translating this improvement into the sizing of the GHX serving as a heat source or sink for the building's mechanical system can be less intuitive.

The physical characteristics of GHX, such as borehole diameter, nominal pipe diameter, pipe thickness, spacing, grout properties, and formation properties, contribute to the effectiveness of this approach. The peak block loading applied by the building or collection of buildings determines the number and depth of BHX. A building with significant heat loss requires more heat to offset building losses, leading to increased annual full load heating and hours on the GHX. The impact of a poorly performing building increases the ground-loop size, thereby raising capital costs. For this reason, investing in a well-insulated, well-constructed building with high-performing windows and a shading option where possible proves essential. The investment in building efficiency reduces the size of the thermal energy network, regardless of technology selected, and lowers operating costs.

The Silo City project illustrates the challenges of historic preservation requirements imposed by the NYS Office of Parks, Recreation and Historic Preservation, which prohibits energy efficiency measures such as adding external façades or interior insulation. The resulting inefficiency of the building envelope led to increased heating requirements for this project, requiring significantly more heating hours than normally expected for a similar building with energy efficiency measures. This situation resulted in trade-offs between cost and carbon savings (NYSERDA, 2022h, p. 13).

3.3 Address System Energy Efficiency

The ASHRAE Standard 90.1 (2022) introduced a new path for HVAC compliance known as the total system performance ratio (TSPR). This ratio is calculated as follows:

Equation 2.

$$\mathbf{TSPR} = \frac{\textbf{Heating + Cooling Loads Delivered}}{\textbf{Annual HVAC Operating Input}}$$

The HVAC operating input can be expressed in terms of energy cost, use (site or source British thermal units, or Btus), or carbon emissions. A higher output of HVAC loads relative to HVAC input indicates a more efficient HVAC system. This compliance approach no longer relies on a component-by-component efficiency, but instead evaluates the combined energy efficiency of all components working together as a system. In summary, total system performance ratio measures total system performance, including both heating and cooling.

This approach aligns with the discussion in Section 2.6, whereby the same result is desired, a system efficiency value. Manufacturers provide COP and EER as efficiency ratings for individual heat pump performance. To establish a similar metric for overall system efficiency using COP (heating) and EER (cooling), calculations must account for all pumping power, as well as for situations where heating and cooling are met by central air handling systems, such as indoor fan coil units, variable air volume boxes, and large multizone air handlers; all fan power must be included.

Considering system efficiency becomes increasingly important, especially with system designs ranging from distributed packaged heat pumps connected to an ATL to a central plant system distributing hot and chilled water to buildings within a thermal energy network. The anticipated ANSI/CSA/IGSHPA C448 Series 25 Standard will likely require a minimum COP value for such systems.

For estimating the HVAC system heating and cooling efficiency, consider using the HVAC System Heating and Cooling Efficiency Calculator, which may be accessed here: https://geokiss.com/free-design-software/

3.4 Current Software Packages Available for Ground Heat Exchanger Design

A case study of the Lincoln, NE, schools by Oak Ridge National Laboratory (Shonder, 2000), validated several software tools available to designers at that time. The author compared the performance of the ground loop with the calculated values provided by each software tool (p. 48). Three of the four tools evaluated for one-year and 10-year design lengths in bore ft/ton correlated well (within +/-12%) with the measured data and the benchmark, which was the Transient System Simulation Tool (TRNSYS). Two of these three correlated software tools remain available today: GLHEPro and GshpCalc.

These tools eliminate rules-of-thumb designs, which pose risk to residential designs and become even more risky to commercial and district-scale system designs.

Following is a current list of commercial software design tools in alphabetical order. Other than the two previously noted tools, whether any of these tools have been verified with measured data from installed ground-loop systems is uncertain. However, all tools likely employ one of the GHX sizing design formulas referenced in the *HVAC Applications Handbook* (ASHRAE, 2023, pp. 35.8–35.18). Users should review the fact sheets for these products before purchasing and applying the software tools to their designs.

- Ground Loop Design (GLD) by Gaia Software
- GLHEPro by Oklahoma State University
- GshpCalc by Steve Kavanaugh
- LoopLink Professional (LoopLink PRO) by GeoConnections[2]

For hybrid design, a software modeling tool has been developed to compare various conventional and hybrid design approaches for building mechanical equipment. Sizing of the ground loop will still occur using one of the previously mentioned tools.

- Hybrid Ground-Coupled Heat Pump (HyGCHP) Modeling Tools by Slipstream

3.5 Design Metrics

Metrics are parameters of a project, typically presented on a unit basis. These project parameters may fall into several categories, such as capital cost, design performance, operational performance, and operational costs, including maintenance. The PON 4614 studies are feasibility studies, meaning any performance or cost metrics will be based on predictions. However, numerous parameters must be determined to complete even a feasibility study. Analyzing these parameters across the projects of PON 4614 can provide useful insights into the technologies proposed. A list of these metrics appears in Table 8 through 14.

Many of the metrics in Table 8 through 14 will be familiar to those designing geothermal heat pump systems and district energy systems. One exception will likely be the line heating and cooling density. This parameter, used in Northern Europe, characterizes load density by measuring the amount of heat delivered annually to consumers within a district or subset thereof for each unit of the distribution system (in trench length) that must be installed to serve the district or subdistrict. Phetteplace and colleagues discuss values that have proven economically viable for conventional low-temperature hot water district heating in Northern Europe (2013, p. 2.5-2.6). Gathering data for the line heating and cooling density in community heat pump-based district energy systems will establish essential benchmarks for assessing the economic viability of concepts such as ATLs, which have no existing database, in contrast to that which low-temperature hot water district heating has in Northern Europe.

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[2] LoopLink PRO uses source code from GshpCalc.

Table 8. Recommended Metrics: Borehole Heat Exchange and Foundation Heat Exchange

Metric	Units (IP)
BXH or FHX Physical Data	—
- BHX Identifier	name
- BHX Grid (if rectangular)	# of bores X # of bores
- BXH or FHX Spacing	ft
- BXH or FHX Depth	ft
- Total # of Bores or Piles	—
- FHX, # of Loops per Pile	—
BXH or FHX Loading and Operating Temperature	—
- BHX or FHX Loading	ft/ton
- If hybrid, Percent Peak Block Load Carried by BHX or FHX	%
- Annual Cycle Min. BHX or FHX Leaving Liquid Temperature	F
- Annual Cycle Max. BHX or FHX Leaving Liquid Temperature	F
- Antifreeze Type (if used)	—
- Antifreeze Protection Temperature	F
BHX or FHX Thermal Properties (measured or assumed)	—
- Thermal Properties Test	Yes/No
- Number of Thermal Properties Tests	–
- Undisturbed Ground Temperature	F
- Thermal Conductivity	Btu/hr-ft-F
- Thermal Diffusivity	ft^2/day
- Grout Thermal Conductivity	Btu/hr-ft-F
BHX or FHX Cost	—
- Permitting Cost	$
- BHX or FHX Specific Cost (drilling, pipe, grout)	$/ft
- Cost of Drilling Spoils Disposal	$
- Headering Cost	$
- Vault Cost (if included)	$

Table 9. Recommended Metrics: Sewage Heat Exchange

Metric	Units (IP)
Sewage Treatment Stage and Properties	—
- Location of SHX Offtake (within collection system, at treatment plant intake or outlet)	—
- Undisturbed Sewage Temperature (annual range)	F
- Available Flow (Min.)	gpd
- Time of Year of Min.Flow	month
- Piping Required from Offtake Point to SHX	ft

Table 9. (continued)

Metric	Units (IP)
SHX Methods	—
- Heat Exchanger Type (plate and frame, immersion panels, immersion tubes, etc.)	—
- Heat Exchanger Approach Temperature	F
- Heat Exchanger Surface Area	ft2
- Maximum Expected Fouling Factor	—
- Cleaning Methods	—
- Expected Cleaning Frequency	—
SHX Cost	—
- Permitting Cost	$
- Connection Cost at Offtake Point	$
- Installed Cost of Connecting Piping	$/lf of trench
- Pumping Station Cost	$
- Annual Pumping Cost	$/yr
- Annual Maintenance Cost as Percentage of Capital Cost	%

Table 10. Recommended Metrics: Open-Loop Groundwater Heat Exchange

Metric	Units (IP)
Production Well Properties	—
- Ground Water Temperature	°F
- Depth to Water Table	ft
- Required Well Capacity	gpm
- Well Specific Capacity	gpm/foot
- Piping Required from Offtake Point to HX	ft
Water Disposal	—
- Disposal at Surface or Reinjection	—
- Distance from Production Well	ft
- Reinjection Well Head Requirement	gpm/ft
Isolation Heat Exchanger	—
- Heat Exchanger Type	—
- Heat Exchanger Approach Temperature	F
- Heat Exchanger Surface Area	ft^2
- Building Side Flow Rate at Peak Block Load	gpm/ton
- Well Waterside Flow Rate at Peak Block Load	gpm/ton
- Expected Cleaning Frequency	—

Table 10. (continued)

Metric	Units (IP)
Well Cost	—
- Test Well Cost	$
- Production Well Cost	$
- Disposal Method Costs	$
- Lateral piping Costs	$
- Production Pump Cost	$
- Annual Pumping Cost	$/yr
- Annual Maintenance Cost as Percentage of Capital Cost	%

Table 11. Recommended Metrics: Distribution Piping System Data

Metric	Units (IP)
Distribution Piping District Data	—
- Number of Connected Buildings	—
- Total Piping Length (excluding laterals to buildings)	ft
- Total Lateral Piping Length	ft
- Min. Burial Depth	ft
- Max. Burial Depth	ft
- Weighted Average Burial Depth	ft
Distribution System Type, Loading, and Operating Temperatures	—
- Type of distribution (1-pipe ATL, 2-pipe ATL, 2-pipe, or 4 pipe)	—
- Heating Season Max. Supply Temperature	F
- Heating Season Min. Return Temperature	F
- Cooling Season Min. Supply Temperature	F
- Cooling Season Max. Return Temperature	F
- Line Heating/Cooling Density	MWh/yr-lf of trench
Distribution Piping Materials and Sizing	—
- Distribution Piping Material(s)	—
- Method of Pipe Joining	—
- Max. Pipe Diameter	in.
- Insulation Thickness (if used)	in.
- Insulation Material	—
- Preinsulated or Field Fabricated Piping	—
Distribution System Costs	—
- Franchise Fees	$/yr
- Distribution System Installed Cost (excluding laterals)	$/lf of trench
- Installed Cost of Laterals	$/lf of trench
- Annual Maintenance Cost as Percentage of Capital Cost	%
- Annual Average Heat Loss/Gain as Percentage of Heat Transported	%

Table 12. Recommended Metrics: Water-source Heat Pump Performance

Metric	Units (IP)
Water-Source Heat Pump Performance	—
- COP at Standard Conditions for Testing and Rating Heat Pump Performance	dimensionless
- COP at Winter Design Source Water Temperature	dimensionless
- EER at Standard Conditions for Testing and Rating Heat Pump Performance	Btu/W-hr
- EER at Summer Design Water Source Water Temperature	Btu/W-hr

Table 13. Recommended Metrics: Air-Source Heat Pump Performance

Metric	Units (IP)
Air-Source Heat Pump Performance	—
- COP at Standard Conditions for Testing and Rating Heat Pump Performance	dimensionless
- COP at Winter Design Air-Source Temperature	dimensionless
- EER at Standard Conditions for Testing and Rating Heat Pump Performance	Btu/W-hr
- EER at Summer Design Air-Source Temperature	Btu/W-hr

Table 14. Recommended Metrics: Life-cycle Cost Analysis Parameters

Metric	Units (IP)
LCCA Parameters	—
- Real rate (excluding inflation)	%
- Nominal rate (including general price inflation)	%
- Inflation for Natural Gas or Other Fuels	%
- Inflation for Electricity	%

3.5.1 Require the Outline of Resiliency Plan

For all future feasibility studies, solution providers must supply more information regarding plans for thermal energy network system resiliency. In addition to the sources cited in Section 2.7, which discusses the topic of resiliency in more detail, additional guidance may be found in the following two publications. The first publication is Guide Brief 5 by NIST for Assessing Energy System Dependencies. The second publication is a Community Resiliency Planning Guide for Buildings and Infrastructure Systems.

- NIST Special Publication 1190GB-16, which may be found here: https://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.1190GB-16.pdf
- NIST Special Publication 1190GB-5, which may be found here: https://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.1190GB-5.pdf

Both publications may be beneficial to solution providers during the development of resiliency plans for thermal energy networks.

3.6 Move toward District Energy System Nomenclature for Clarity

Although the term "thermal energy network" has been legislated in New York State, the industry standard terminology for the technologies discussed herein is "district energy systems." NYSERDA and other industry stakeholders should clearly define these terms and their relationship to accepted industry language. The following definition is from the ANSI/CSA/IGSHPA C448 Series 25 Standard:

> **District Energy Systems** are characterized by one or more central plants distributing ambient water, hot water, water-based solutions, steam, and/or chilled water, which then flows through a network of pipes to provide hot water, space heating, and/or air conditioning for multiple buildings. Central plans are inclusive of pumping stations or plants which can be employed as part of a district energy system using the earth, groundwater, and/or surface water as a source or sink in the distribution system.
>
> District energy systems include ambient temperature loop systems, combination systems, and can include site-generated power or energy storage.
>
> District energy systems are also known as "district heating and cooling systems," "district geothermal systems," "community heat pump systems," "fifth and sixth generation district heating and cooling systems," "thermal energy networks," and "utility thermal energy networks."

3.7 General Recommendations for Future Thermal Energy Network Program Opportunity Notices

To improve the effectiveness and clarity of future thermal energy network PONs, here are some general recommendations:

- For future PONs, project developers should match feasibility study funding. This investment demonstrates commitment to the project and could be helpful in securing funding needed to advance the project into the design phase. When determining which studies to fund, stakeholders should compare the likelihood and impact of success against associated cost (funding at risk).
- The analysis of costs and financial estimates were adequate, except for the pricing of the thermal energy network distribution piping component. Future estimates should require more detailed cost breakdowns, citing pricing sources, and consider site challenges, pipe types, insulation if required. Costs must include all factors, including pipes, fittings, pipe joining, field insulation of joints, waterproofing where applicable, trenching, backfilling, and surface restoration. Section 2.2 provides further explanation, and Section 3.5 has examples of incorporating this into future PONs.
- Each proposal should present one proposed alternative to the existing or business-as-usual system. While evaluating multiple alternatives is acceptable, one must take priority, with clear reasons cited.

- Consider requiring a statement regarding any target of opportunity sources or sinks in the vicinity. This includes evaluating open-loop or water well options, including pump-and-treat methods. Although many locations in New York State may disfavor open-loop solutions, certain locations could benefit from this option, so it should not be dismissed outright. When possible, open-loop options offers advantages and can be implemented in an environmentally sound manner, as discussed in Section 2.
- Require a thermal conductivity (TC) test or perform a sensitivity analysis of the anticipated range of thermal properties (thermal conductivity, thermal diffusivity, and undisturbed earth temperature) at the project location. The anticipated range of properties may derive from thermal conductivity tests conducted in nearby projects, analyses of local water well logs, or investigations of geotechnical and soil reports. The sensitivity analysis should also consider a range of undisturbed ground temperatures for the project location. For example, a thermal conductivity test in New Paltz, NY, recorded an undisturbed ground temperature of 52°F, while a thermal conductivity test in Battery Park in New York City lists an undisturbed ground temperature range of 58°F–60°F. This analysis will clarify the uncertainty in project costs for the developer or future building owner.
- Many figures in the reports are too small or unclear to interpret accurately. NYSERDA should consider establishing a standard format or size guideline for future PONS. Several tables were too small, and in some cases, simply switching to landscape orientation could enhance readability. Half of the studies were ongoing during the review process, so these issues may have been addressed in the final reports.

3.8 Recommended Template for the Distribution Piping of a Thermal Energy Network

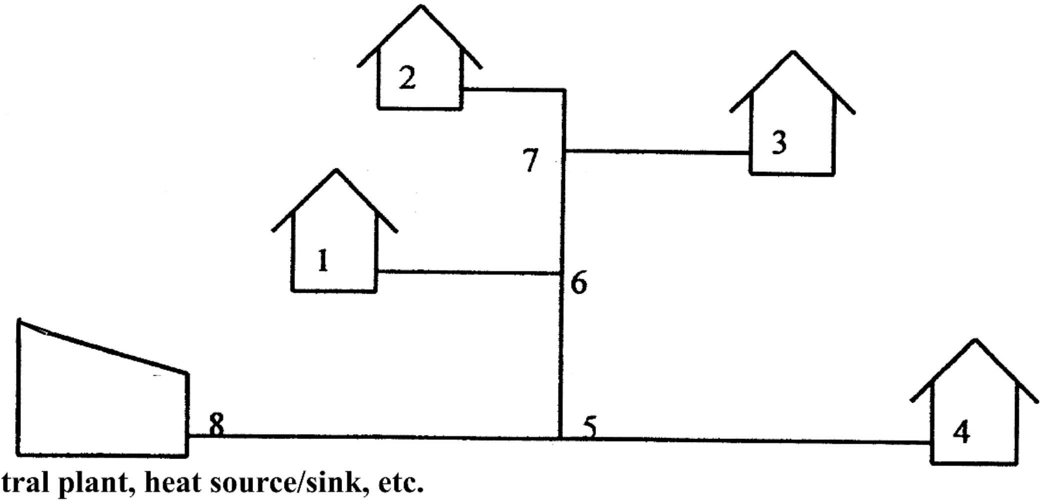
The distribution system piping between buildings and sources or sinks constitutes a major portion of the initial investment for many thermal energy networks. For this reason, proposers must meet certain minimum requirements to facilitate evaluation of their proposals and demonstrate their understanding of the distribution system requirements. This requirement is in addition to providing schematic diagrams and illustrations that convey the overall layout of the system, including local benchmarks; for excellent examples, see “Syracuse District Energy System” (NYSERDA, 2022c).

3.8.1 Simple Illustration of Thermal Energy Network

Phetteplace (1994) provides a basic template for labeling the piping of a distribution system, sources and sinks, and connected buildings. The first component of the template is a simple drawing, as shown in Figure 6.

Figure 6. A Simple Illustration of Thermal Energy Network with Two-Pipe, Tree Structure

Source: Adapted from Phetteplace (1994).



The numbers in Figure 6 represent nodes. A node may be a heating or cooling consumer, a heat source or sink, a pumping plant, or a junction in the piping network. The basic characteristics of the nodes in this figure are in Table 9, also from Phetteplace (1994).

3.8.2 Tabulating Distribution System Information

Table 15. Node Functions, Elevations, and Maximum Demand Assigned for Figure 6 Example

Node Number	Node Type	Elevation (m)	Maximum Demand (kg/sec)
1	Heat consumer	40	10
2	Heat consumer	30	10
3	Heat consumer	20	10
4	Heat consumer	10	10
5	Pipe junction	0	—
6	Pipe junction	0	—
7	Pipe junction	0	—
8	Heating plant	0	-40

The piping between nodes is referred to as segments. In the case of a two-pipe system, each segment, while drawn as a single line, represents both supply and return pipes. Data for the pipe segments will be an important portion of the feasibility study data. Table 10 shows some data for the simple example illustrated in Figure 6.

Table 16. Pipe Segment Data Table

Pipe Segment	Segment Length (m)	Elevation Change (m)	Maximum Flow Rate (kg/sec)	Nominal Pipe Dia. (mm)	Unit Cost[a] ($/m)	Segment Capital Cost ($)
6, 1	100	40	10	65	$2,000	$200,000
7, 2	25	30	10	65	$2,000	$50,000
7, 3	50	20	10	65	$2,000	$100,000
5, 4	100	10	10	65	$2,000	$200,000
6, 7	50	0	20	100	$2,300	$115,000
5, 6	100	0	30	100	$2,300	$230,000
8, 5	200	0	40	125	$2,600	$520,000

[a] In buried piping systems for district energy, customary practice includes unit length costs that encompass all pipes within the trench, whether one, two, or more. This approach eliminates the need to prorate costs such as trenching, backfill, and surface restoration to each pipe.

Design flows, rather than heating and cooling loads, are provided; thus, a design delta T must be provided to translate the flows into heating or cooling loads. When heat pumps within buildings receive service from the distribution system, the building design heating and cooling load will differ from the design load imposed on the distribution system due to heat of compression from the heat pumps.

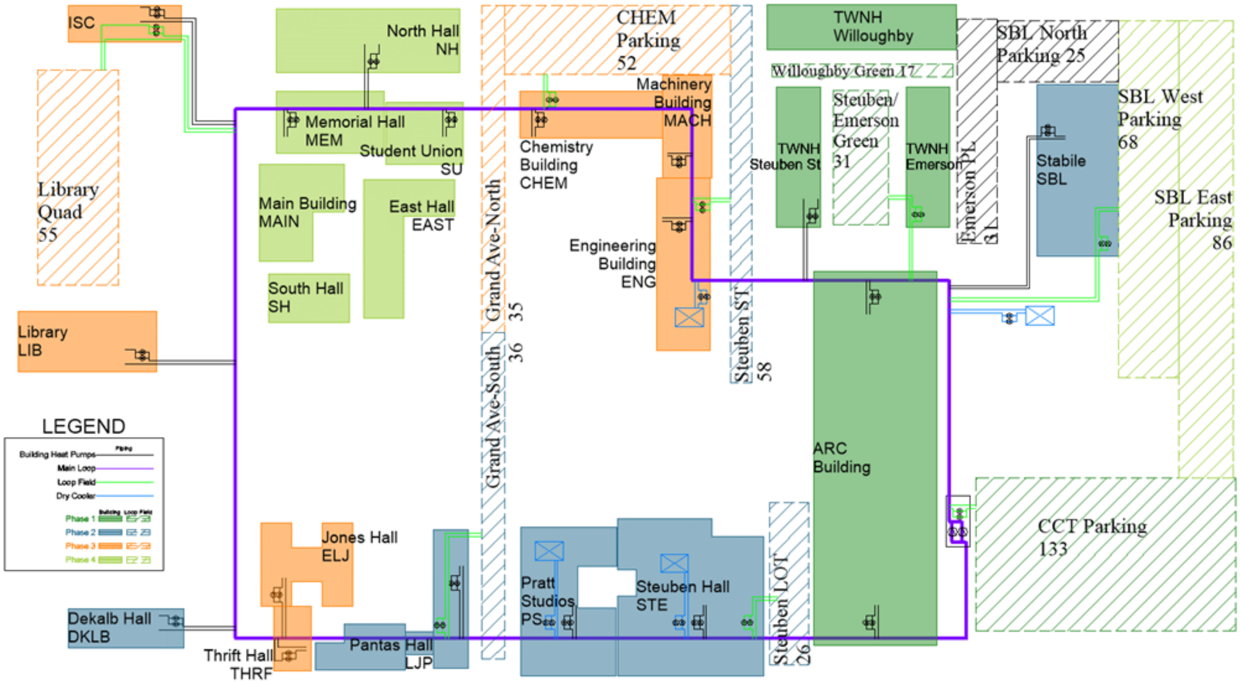
The distribution system shown in Figure 6 is of the tree-type structure often found in traditional district heating and cooling systems. In a thermal energy network with distributed heat pumps, an alternative loop-type system is possible. The simplest type of distribution piping for a thermal energy network, known as an ATL, can consist of either a single central pipe in a loop configuration or multiple pipes. Figure 7 shows a one-pipe ATL, where the one-pipe portion refers to the piping labeled as the main loop. Each building or heat source or sink is close-coupled by a supply-and-return pipe to the central one-pipe loop, leading to potential differences in node numbering of nodes compared to that shown in Figure 6. However, all the necessary information to estimate the distribution system should be included, encompassing both the central one-pipe loop and the close-coupled lateral interconnection piping.

Although developing a tabular format to contain all information from Tables 9 and 10, as well as the fluid temperatures in the central loop, falls outside the scope of this report, such a format is recommended. This will ensure that the proposer considers the diversity of loads in the community heat pump system (CHPS), and their impact on central loop temperatures and required flow rates. Additionally, accounting for the impacts of heat losses and gains to or from the surrounding soil will help ensure that temperatures throughout the loop do not approach freezing where antifreeze is not used, as discussed in Section 2.2.

An ATL system can also be designed as a two-pipe system, which removes the constraints on arranging building loads and heat sources or sinks in a manner that precludes central loop temperature becoming too low or too high for in-building heat pumps throughout in the loop. Additionally, any two-pipe system may incorporate loops, thus creating a hybrid of tree and loop-type distribution piping. Often loops are added to a basic tree-type distribution system to introduce redundancy.

Figure 7. Typical Ambient Temperature Loop Schematic

Source: "Community Heat Pump Feasibility Study, Pratt Institute, Main Brooklyn Campus, Final Report" (NYSERDA 2202b, p. 71).



4 Awareness and Future of the Industry

4.1 Grid Interactive Buildings

In October 2023, ASHRAE published a new design and operation resource guide titled, "Grid-Interactive Buildings for Decarbonization." This guide focuses on both commercial and MF buildings. Instead of relying on the current one-way communication signal between a utility and a building, the guide encourages utilities to provide two-way communication. This change will foster greater interaction between a utility and the building, enabling demand flexibility through controls to reduce carbon emissions, co-optimize operations to minimize both carbon emissions and energy cost, and evaluate other key objectives relevant to each building.

Many building owners resist this concept, believing that utility companies will dominate their building. However, utilities could communicate with building owners to inform them about changes in carbon emission factors, pricing, and power availability, while recommending operational adjustments. Ultimately, building owners must respond to the utility and decide whether to accept or reject any proposed changes to meet their baseline energy demands. The guide outlines three groupings of grid-interactive operations: event-based load modification, load shaping, and rid-ancillary services. Given this opportunity for two-way communication, building owners should develop a cybersecurity plan.

Although this idea is in its infancy, several pilot projects are underway that reveal challenges and develop solution to these challenges. Various approaches to communication architecture for building integration are being explored. While some are best distributed, others are integrated with the building automation systems (BAS). Several grid-interactive building communication platforms, including DNP3, OpenADR, and IEEE 2030.5, offer different capabilities. DNP3 offers the least flexible two-way communication between the utility and a building, allowing only basic on/off or yes/no interactions. In contrast, other communication formats provide more flexibility, and some utilities are already using them.

> The guide outlines best practices for the infrastructure and equipment required for future grid integration of buildings. For example, "In cases where tenant-occupied spaces have utilities costs paid by the building owner and the building owner is responsible for the building's carbon emissions, the owner is incentivized to invest in both energy-efficient systems and grid-interactive smart appliances, thermostats, and control systems." (ASHRAE, 2023a, p. 11)

> It provides general best practices for grid integration, along with design and operational guidance for both standalone and integrated systems, and includes a section for portfolios, campuses, and districts. These buildings contribute to the reliability, decarbonization, and affordable operation of the electric grid by managing loads while meeting occupant needs and preferences and benefit from lower carbon emissions, reducing operating costs, and increased resiliency as compared to a typical building. (ASHRAE, 2023a, p. 3)

4.2 Heat Pump Equipment Offerings

In interviews with solution providers, one challenge emerged: heat pump technologies commercially available in European or global markets were not available in the U.S. The U.S. heat pump market lags years behind its European counterpart, limiting options, particularly for projects using variable refrigerant flow (VRF) as the baseline system. One solution provider initially intended to develop a GSHP/ASHP hybrid system rather than placing GSHPs and ASHPs on separate circuits. Discussions with equipment providers revealed that the technology to support that solution is only available in European markets, although it should be available in the U.S. in the coming years. From this interview we understand that although the U.S. market has variable refrigerant flow GSHP modules, they are intended to support full-load geothermal projects rather than hybrid solutions. Solution providers note that heat pump manufacturers recognize a growing market opportunity in the U.S., which should lead to a broader range of offerings in the next few years.

This study also found that while heat pump hot water heaters capable of producing high temperatures are available on the U.S. market, they are not available in the 208-volt configuration common to the New York City area grid.

4.3 Role of District Energy Systems in Decarbonization

Most U.S. citizens struggle to see district energy as a significant player in decarbonization, given its uncommon presence here. Although feasibility studies of PON 4614 on community heat pump systems have helped broaden the perspectives of those involved, efforts must be expanded. In Europe, where district energy systems are much more commonplace, these systems are recognized as essential for decarbonization. A recent publication from Aalborg University in Denmark highlights three key points from their examination of space heating in the European Union (EU):

- “Countries where district heating is well-established not only have lower natural gas dependence in the heating sector, but also have a lower reliance on fossil fuels in individual heating” (Mathiesen et al., 2023, p. 2).

- “Two-thirds (9 out of 14) of the countries where district heating has a market share below 20% have a reliance of half or more on fossil fuels in individual heating” (Mathiesen et al., 2023, p. 2).
- “Individual boilers firing fossil fuels represent over 70% of the heat market in the 10 countries where district heating has a market share of about 10% or below e.g., Germany, Italy, Belgium, Ireland, and the Netherlands” (Mathiesen et al., 2023, p. 2).

Mathiesen and colleagues conclude that these findings illustrate how the role of district heating is underestimated in the European Union (2023, p. 2). If the penetration of district heating in the U.S. is evaluated against this yardstick, the underestimation of district heating potential is even greater. Breaking through this barrier and leveraging district energy for decarbonization remains critical.

While ATLs represent a valid approach to district energy, gaining the most interest in the PON 4614 studies, other approaches must be considered to fully realize district energy’s potential across a wider range of applications. Europeans have embraced ATLs, but they have not focused exclusively on this approach. Recent Euro Heat and Power award winners featured projects that recover heat from data centers with two-stage heat pumps, combine solar thermal with thermal storage and biomass, and use pit thermal storage at temperatures up to 194°F to increase heat recovery from waste-to-energy plants. All of these projects used more conventional district heating supply temperatures, typically 70 degrees Celsius (°C; 158°F) for supply and 50°C (122°F) for return. While pushing to lower supply temperatures is advantageous for heat pump usage, lower supply temperatures are incompatible with many of the in-building heat delivery systems, necessitating significant investments to remove this obstacle.

The PON 4614 studies largely focused on solar photovoltaic technology as a renewable energy source, which is more suited to coupling with the electric grid than with thermal energy networks, as is the case for thermal energy storage (TES). Solar photovoltaic systems require storage to achieve their potential, but storing electricity in batteries is expensive, costing about twice as much as thermal energy storage using water in steel tanks (Phetteplace et al., 2019). Current battery storage technology offers only 85% round-trip efficiency (2019), compared to thermal energy storage, which incurs minimal losses of only a few percent for short-term storage. Finally, the lifetime of thermal energy storage in steel tanks is about five times longer than that of batteries (2019). Considering these factors alongside the efficiency differences—approximately 80%

for thermal solar collectors compared to about 20% for solar photovoltaic collectors—future studies should prioritize pairing thermal energy storage with thermal energy networks. This focus has gained more prominence in Europe. And while significant differences exist between energy delivery in the U.S. and Europe, much can still be learned from European practices, especially regarding district energy.

4.4 A2L Refrigerant Impacts

A2L refrigerants are the next generation of refrigerants to which many equipment manufacturers currently using A1 refrigerants will transition over the next two years because of their lower global warming potential. The A2L is a designation and safety classification for refrigerants, as identified in the American National Standards Institute (ANSI)/ASHRAE Standard 34-2022. The “A” indicates lower toxicity, while the “2L” signifies lower flammability. Refrigerants in use today are classified as A1, which are low toxicity and are nonflammable. For building owners, the lower flammability classification means that safety requirements will apply to both designers and installers. Additionally, any gas-fired equipment may not be co-located in a mechanical space with equipment using these new refrigerants.

For small packaged heat pump equipment that include a charge of refrigerant of 64 ounces or less, no sensing or mitigation is required. However, for equipment housing or distributing refrigerant, such as variable refrigerant flow systems, refrigerant volumes exceeding 64 ounces will require mitigation upon leak detection. This mitigation will require venting through ductwork into a large, occupied area or venting directly outside with a specified cubic feet per minute through a ventilation duct.

Installers must comply with the Underwriters Laboratories (UL) 6335-2-40 Safety Standard, which took effect on January 1, 2024. This standard mandates, among other requirements, special labeling on the new equipment that use the A2L refrigerants various leak detection system requirements. The current phase-out plan for high global warming potential (GWP) refrigerants used in new equipment is as follows:

- January 1, 2025, for chillers
- January 1, 2025, for heat pumps and air conditioners
- January 1, 2026, for variable refrigerant flow and variable refrigerant volume (VRV) systems

4.5 New Standards: American Heating and Refrigeration Institute 600 and 1600

These new standards aim to update the performance rating protocols for residential and small commercial water-to-air heat pumps that have been in use by the geothermal industry for more than 30 years.

AHRI 600-2023 has been adopted and will gradually replace ANSI/AHRI/ASHRAE International Organization for Standardization (ISO) Standard 13256-1 over the next few years. During this transition, both standards will appear on equipment performance information sheets until the ISO standard is phased out.

The scope of AHRI 600-2023 covers factory-made water/brine-to-air heat pumps. This standard introduces new efficiency metrics, making the comparison of ASHPs to water-source equipment performance simpler.

The new metrics, integrated energy efficiency ratio (IEER) and average coefficient of performance (ACOP), will replace the previous EER and COP, respectively. Understanding what is, and is not, included in these new efficiency values will require some time to fully comprehend.

While the performance rating conditions remain similar to those used in the past, the new standard also accounts for some pumping and fan power for ducted systems, as well as filter pressure drop.

AHRI 1600 will be the new standard for residential ASHPs, set to replace AHRI 210-240 starting in 2029.

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