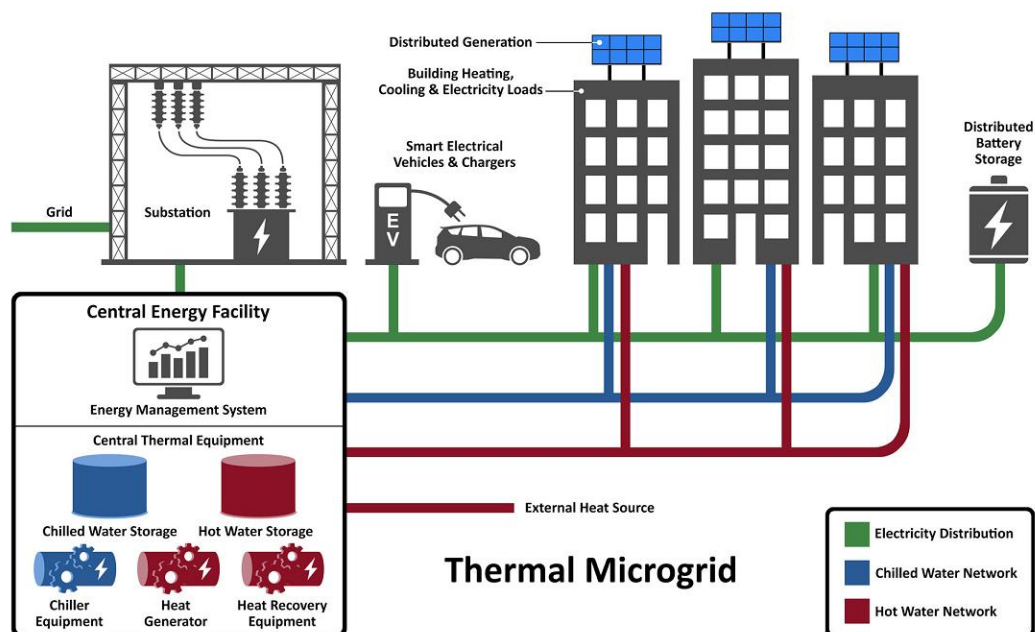


# Thermal Microgrids: A Tool Suite Guide for Feasibility Assessment



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## About this Guide

This guide was completed as a part of a collaboration between EDF Innovation Lab, Stanford University and the City of Palo Alto Utilities for the project *Leveraging Experience from Stanford and EDF to Develop Information and Tools for Thermal Microgrid Feasibility Assessments*, co-funded by EDF and the American Public Power Association (APPA) Demonstration of Energy & Efficiency Developments (DEED) program. The project objective is to provide information and tools to support municipal utilities in evaluating the feasibility of deploying thermal microgrids. Deliverables of the project include i) a white paper describing the technology, economics, and market of thermal microgrids and comparing them to alternatives; ii) a case study report describing the Stanford Energy System Innovations (SESI) project, in which their campus-wide cogen system was transformed into renewable electricity powered heat recovery with low-temperature hot water distribution; iii) a suite of tools and guidance for assessing technical and economic feasibility (this report); and iv) two municipal case studies applying the tools to carry out feasibility assessments.

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## Executive Summary

As introduced in the thermal microgrid white paper<sup>1</sup> (Part 1 of the project), energy efficiency efforts and the combination of electrification and clean electricity are required to achieve a sustainable building energy future. This conclusion is based on multiple studies carried out across the energy community and driven by the techno-economic feasibility of decarbonizing electricity as opposed to using renewable natural gas or transitioning to other fuels such as hydrogen. While power and electric cooling in buildings are made sustainable via clean electricity, heating and hot water have traditionally been supplied using fossil fuels such as natural gas, and thus require a switch to a new electrification approach.

The development of ultra-high-efficiency electric heat pumps provides a path for large-scale building decarbonization<sup>2</sup>. Heat pumps can harvest heat from the ground, water, or air, as well as recapture waste heat. A heat recovery chiller is a type of heat pump that recaptures waste heat from the chiller process and is ideally suited for simultaneous heating and cooling needs (which often does exist in large campuses). Thermal microgrids or district energy via advanced electrification has a number of cost and environmental advantages compared to building-level electrification alternatives, including 1) economies of scale, 2) efficient design based on load/resource diversity, 3) cost-effective waste heat recovery technologies that are infeasible at the building-level, 4) thermal energy storage that can enhance waste heat recovery simultaneously with enabling the provision of grid services, and 5) mitigation of over-sizing of equipment to meet peak demand. Furthermore, district energy systems have the potential to change the otherwise slowly-moving building sector rapidly. Since two-thirds of building energy use is thermal, the opportunity to realize massive greenhouse gas emissions reductions is vast. Coupling building electrification with waste heat recovery, energy storage, and model predictive control in a district energy system can achieve dramatic greenhouse gas (GHG) reductions and efficiency improvements (30-70%).<sup>3</sup>

This report is Part 3 of the project and explores the tools that are currently or soon-to-be available that municipalities can use to carry out a complete pre-feasibility and feasibility assessment of a thermal microgrid. This resource could also be used by energy managers of large campuses such as universities and hospitals to help plan for electrification. These energy systems are typically designed to operate for 30 plus years and require significant capital commitment. Therefore, an initial quantification of life-cycle costs, savings, and environmental impacts as compared to business as usual are important for the decision makers.

This paper covers a comprehensive list of software tools, ranging from Excel macros to licensed, standalone software programs. We have examined capabilities of thirteen applicable tools, listed their

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<sup>1</sup> *Thermal Microgrids: Technology, Economics & Potential*, 2018. [http://www.edf-innovation-lab.com/wp-content/uploads/2018/06/20180517\\_ThermalMicrogrid\\_WhitePaper\\_FINAL.pdf](http://www.edf-innovation-lab.com/wp-content/uploads/2018/06/20180517_ThermalMicrogrid_WhitePaper_FINAL.pdf)

<sup>2</sup> Electric heat pumps are commercially available and are much more efficient than natural gas appliances. Heat pumps typically obtain a COP of 3 (or equivalent efficiency of 300%) whereas efficiency of natural gas boilers is around 85%

<sup>3</sup> *Stanford's "4th Generation" District Energy System: Comb. Heat & Cooling Opens Path to Sustainability*, 2018. [http://www.edf-innovation-lab.com/wp-content/uploads/2018/06/2018\\_SESICaseStudy\\_FINAL.pdf](http://www.edf-innovation-lab.com/wp-content/uploads/2018/06/2018_SESICaseStudy_FINAL.pdf)

data requirements, forms of outputs provided, and other requirements (such as licensing fees). We also performed a benchmarking of these tools with an objective of identifying an easy-to-use tool, which uses data sources available to municipal planners and which can model new electrification technologies for the North American region. After the benchmarking, we have selected two tools - CEPOM and RETScreen - and have proposed a preliminary step-by-step guide for modeling a thermal microgrid system.

In the review process, there were certain limitations of existing tools that became apparent. None of the existing tools fulfilled the desired thermal microgrid assessment objectives. Therefore, we've proposed a vision for a future, an optimal tool that uses publicly available databases in combination with machine learning techniques to estimate thermal loads with at least an hourly resolution, to properly size a thermal microgrid to meet peak demands. The optimal tool should automatically calculate cost savings, emissions reductions, water use reductions, and other socio-technical or techno-economic impacts of the thermal microgrid versus the business-as-usual case. Overall, the development of an optimal tool for thermal microgrid assessment remains an area of further research and development.

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# 1 Background and Overview

According to the United Nations, 68% of the world's population will live in urban areas by 2050<sup>4</sup>. Furthermore, cities currently contribute more than 70% of all anthropogenic carbon dioxide emissions<sup>5</sup>. Therefore, to achieve GHG emission reduction targets, the use of carbon-based fuels must be reduced in urban areas. As discussed in Part 1 of the project (thermal microgrid whitepaper<sup>6</sup>), buildings are responsible for approximately 40% of all energy usage within the U.S. and a third of emissions, a significant portion of which is from appliances burning natural gas and other carbon-based fuels for heating and cooking. Substantial fuel switching in the building sector from fossil fuel to electricity –also called electrification– combined with continued electricity decarbonization and energy efficiency is required to achieve science-based GHG emissions reductions targets.

Part 1 of the project introduced the concept of a “thermal microgrid” that utilizes clean electricity, waste heat recovery, and thermal storage to provide a cost-effective, resilient and sustainable option to meet energy needs for a group of buildings. Part 1 also provided an overview of costs, GHG impact, water usage requirements, and primary feasibility drivers of a thermal microgrid compared to alternatives. Part 2 of the project discussed the development of the Stanford Energy System Innovation (SESI) facility and shared lessons learned by Stanford regarding the design and operation of a “fourth-generation” thermal microgrid system. This paper is Part 3 of the project and aims to provide an overview of the tools available for pre-feasibility and feasibility assessments of a thermal microgrid as compared to business as usual (BAU) or other system alternatives. These energy systems are typically designed to operate for 30 plus years and thus require significant capital commitment. Therefore, an initial quantification of life-cycle costs, savings, and environmental impacts are important for decision makers. As the project moves forward from the conceptual planning phase to the design phase, a detailed engineering analysis will still be needed. These initial pre-feasibility and feasibility tools are needed but are not substitutes for the in-depth engineering design.

The goal of this paper is to inform and enable members of local government (city planners, urban designers, etc.) and municipal utility employees (resource planners, public works engineers, etc.) who may not have detailed thermal microgrid system background. This paper will aid in quantifying the potential benefits of a thermal microgrid and gain buy-in from key decision makers for further assessment. This resource could also be used by energy managers of large campuses such as universities and hospitals to help plan for their campus electrification.

The report is broken down into the following sections:

- Section 2: Overview and benchmarking of existing pre-feasibility/feasibility assessment tools
- Section 3: Step-by-step guide for modeling a thermal microgrid with most applicable tool(s)
- Section 4: Vision for an optimal thermal microgrid assessment tool
- Section 5: Conclusions and Future Work

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<sup>4</sup> <https://www.un.org/development/desa/en/news/population/2018-revision-of-world-urbanization-prospects.html>

<sup>5</sup> [https://www.c40.org/why\\_cities](https://www.c40.org/why_cities)

<sup>6</sup> *Thermal Microgrids: Technology, Economics & Potential*, 2018. [http://www.edf-innovation-lab.com/wp-content/uploads/2018/06/20180517\\_ThermalMicrogrid\\_WhitePaper\\_FINAL.pdf](http://www.edf-innovation-lab.com/wp-content/uploads/2018/06/20180517_ThermalMicrogrid_WhitePaper_FINAL.pdf)



## 2 Existing Tools & Resources for Feasibility Assessments

Currently, there are various tools available for assessing different aspects of district heating and cooling. These tools are developed over the past ten years and vary from spreadsheets to licensed software applications. Each tool is targeted towards a specific region (i.e., Scandinavia, United States), audience (i.e., planner, engineer, etc.), and project stage (i.e., pre-feasibility, feasibility, engineering design).

Our objective is to find an easy-to-use tool that can be applied for pre-project conception, pre-feasibility, or feasibility assessments of thermal microgrids in the United States. We have referenced the energy system planning stages shown in **Figure 1**. These planning stages are adapted from Plan4DE, and this report attempts to maintain consistency with their definitions<sup>7</sup>. An *Operation* stage is also added, to account for the additional capabilities of some tools. Please see Appendix A for additional further reading.

**Figure 1: Planning stages for a district energy system**

	Pre-project conception	Pre-feasibility	Feasibility	Design	Tender or Solicitation	Operation
Scope of Options						
				Engineering models	Detailed costing	
Before Construction	5+ years	3-5 years	2-3 years	1-2 years	0-1 years	-
Cost Estimates	± 20-50%	± 20-50%	± 15-30%	± 5-20%	± 3-10%	M&V

Source: Adapted from Plan4DE scoping document<sup>8</sup>;

Please note that timeline from pre-feasibility and feasibility assessment to design of the project could be reduced if there are easy to use assessment tools available.

### 2.1 Existing Tools Introduction and Summary of Tool Features

This section provides a brief overview of tools reviewed and their relative benchmarking. We performed a comprehensive review of online resources and reached out to the industry experts to

<sup>7</sup> <http://plan4de.ssg.coop/insights/>

<sup>8</sup> [http://plan4de.ssg.coop/wp-content/uploads/2015/06/150217\\_Plan4DE-Scoping-document.pdf](http://plan4de.ssg.coop/wp-content/uploads/2015/06/150217_Plan4DE-Scoping-document.pdf)

understand the functionality of the tools. We have listed below a summary of these tools. Table 1 provides a list of existing tools (in alphabetical order), as well as a summary of their key features and capabilities. Table 2 provides a summary of licensing requirements for these tools, their software type, and online links to download the software.

1. **CEPOM**, short for Central Energy Plant Optimization Model, is a patented technology developed by Stanford University that creates an optimal hourly dispatch for the Stanford Central Energy Facility. The inputs to CEPOM include hourly heating and cooling loads, power demand, electricity price, temperature data, and storage parameters.
2. **DER-CAM**, short for Distributed Energy Resources - Customer Adoption Model (DER-CAM), is a decision support tool that serves the purpose of finding optimal distributed energy resource (DER) investments in the context of either buildings or multi-energy microgrids. It is developed by Lawrence Berkeley National Lab.
3. **DistrictECA**, developed using funding from the German Ministry of Economy and Technology, is a simple tool for planners to use during the initial stages of energy-efficient district design. Featuring a user-friendly graphical user interface (GUI), DistrictECA provides monthly thermal load predictions for the selected buildings at a given site.
4. **DHAT**, short for District Heating Assessment Tool, was developed by engineering consultancy Ramboll for the Denmark Energy Agency. DHAT is used to compare how district heating systems compare to individual heating regarding levelized cost of energy (LCOE), CO<sub>2</sub>, and NO<sub>x</sub> emissions.
5. **EnergyLogic**, developed by EDF R&D, uses Agent-based simulation approach and AnyLogic software package to perform energy system planning. It is a versatile tool that could be customized for thermal microgrids system design.
6. **EnergyPRO**, developed by EMD International A/S, is a commonly used tool for district heating design in Denmark<sup>9</sup>. Given costs, taxes, weather conditions, etc., the EnergyPRO software provides the optimal operation of the energy system being studied.
7. **ETEM**, short for Energy-Technology-Environment-Model, is a bottom-up model that finds optimal energy and technology options at a regional or city level. It is developed by Switzerland based ORDECSYS group and used by EDF R&D in Europe for modeling local energy systems.
8. **EOS**, the enterprise version of Stanford's CEPOM software, is developed by Johnson Controls. It is a new software tool that provides a user interface for the original CEPOM model. The goal of EOS is to create a customizable, in-house solution for entities developing and operating district heating and cooling systems. As of December 2018, EOS is still under development.
9. **HOMER** is an electric microgrid modeling software. It has a variety of software tools which range from optimizing off-grid systems to minimizing demand charges to optimizing behind-the-meter distributed energy resources. HOMER may be adding thermal microgrid features in the future.
10. **NetSim**, developed by Swedish company Vitec software, is used by engineers to plan and build district heating and cooling systems. It is useful for optimizing an existing system, as it can automatically size pipes, and also provides visualizations of temperature and flow within the system.

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<sup>9</sup> Correspondence with Kenneth Hansen, Aalborg University

11. **Plan4DE** was developed using funding from the International Energy Agency to give planners and local governments the ability to assess district energy system feasibility when planning at the neighborhood level. It is meant to be simple yet educational, practical, and persuasive.
12. **RETScreen Expert**, the newest version of RETScreen, was developed by Natural Resources Canada. It is a standalone software tool for performing energy benchmarking, as well as feasibility studies for cogeneration systems. Starting in early 2019, it will support district energy systems.
13. **RETScreen Suite**, the older, Excel-based version of RETScreen, has most of the functionality of RETScreen Expert, minus the standalone component. However, it does support the modeling of district heating and cooling systems.

**Table 1: Summary of Key Features of Assessment Tools**

S.N.	Tool Name	Planning Stage(s)	Scope of Energy System	Input data & resolution	Output
1.	<b>CEPOM</b>	Feasibility Engineering Design Operation	Combined heating and cooling (CHC) systems with thermal storage	<b>Hourly</b> electric, heating, and cooling loads, temp data, electricity cost, hot and cold tank capacity and flow rate, etc.	Optimal dispatch of the energy system, total cost, water use, CO2 emitted
2.	<b>DER-CAM</b>	Feasibility Operation	A wide range of distributed energy resources for meeting electricity, heating and cooling energy needs	<b>Hourly</b> end-use load profiles for a typical year (electric, cooling, refrigeration, space heating, hot water, and natural gas loads), relevant energy tariffs and price data, technology costs, etc.	Optimal selection and capacity of DER to be installed, detailed cost and CO2 emissions breakdown of supplying end-use load
3.	<b>DistrictECA</b>	Pre-Feasibility	A wide range of energy systems from the individual building to district energy assessment;  no option to model electrification for district energy	Building types, location, building equipment	total energy use by type. <b>Monthly resolution</b>
4.	<b>DHAT</b>	Pre-Feasibility	District Heating only, using a variety of heat sources;  no option to model electrification for district energy	Heating and hot water demand, individual buildings and district heating technologies	Costs, emissions, socio-technical parameters
5.	<b>EnergyLogic</b>	Pre-Feasibility	A wide range of energy systems	Heating and Cooling load profile, buildings thermal profile, electricity demand, weather	Total costs, savings, and emissions
6.	<b>EnergyPRO</b>	Feasibility	A wide range of energy systems	Electricity prices, system topology,	Optimal dispatch of energy system

		Engineering Design Operation		heating and cooling loads, equipment data, constraints, etc.	at a <b>user-defined resolution</b>
7.	<b>EOS (Johnson Controls Enterprise Optimization Solution)</b>	Engineering Design Operation	Optimized for combined heating and cooling systems	same as CEPOM	Current system state, planned dispatch of equipment (updated in real time)
8.	<b>ETEM</b>	Feasibility Engineering Design	A wide range of energy systems	Detailed inputs on load and functioning on the distributed energy systems	Optimal design, costs, emissions
9.	<b>HOMER</b>	Feasibility Engineering Design	HOMER Pro tool is great for development and optimization of an electric microgrid.	Load profile, location, equipment (either selected from database or customized).	Optimal hourly dispatch of designed system
10.	<b>NetSim</b>	Engineering Design Operation	District heating and cooling system design and optimization	GIS file of pipe network, central plant parameters, thermal load at each building connection	Optimal sizing of pipes, time-varying animation of temp, pressure in the system
11.	<b>Plan4DE</b>	Pre-Pre-Feasibility	A high-level assessment of district heating options in different areas of a city  No option to model district electrification	District size, climate zone; number and/or total area of each building type	Cost breakdown, comparison (individual vs district heating), cost curve, emissions comparison (CO <sub>2</sub> , SO <sub>2</sub> , NO <sub>x</sub> )
12.	<b>RETScreen Expert</b>	Pre-Feasibility Feasibility	Identification and assessment of potential energy efficiency, renewable energy, and cogeneration projects. Also, used to verify actual	Does not currently support district energy systems, so <b>N/A</b>	<b>N/A</b> at this time

			performance of buildings		
13.	<b>RETScreen Suite</b>	Pre-Feasibility  Feasibility	Similar to RETScreen Expert, but lacking the portfolio analysis	Network topology, existing equipment, location, estimated <b>monthly</b> heating and cooling loads; various emissions and financial parameters	<b>Monthly</b> heating and cooling loads, emissions, IRR, cash flows, system design charts

**Table 2: Summary of Assessment Tools Licensing and Software Type**

S.N.	Name	License & Access	Software Type	Website	Notes
1.	CEPOM	Free* for non-commercial use	Microsoft Excel macro	<a href="https://sustainable.stanford.edu/sites/default/files/IDEA_Stagner_Stanford_fourth_Gen_DistrictEnergy.pdf">https://sustainable.stanford.edu/sites/default/files/IDEA_Stagner_Stanford_fourth_Gen_DistrictEnergy.pdf</a>	Stanford is working with Johnson Controls to convert this excel based model to a standalone application. Future availability of CEPOM is pending licensing agreement between Stanford and Johnson Controls
2.	DER-CAM	Free	Browser-based app and Standalone Application	<a href="https://building-microgrid.lbl.gov/projects/der-cam">https://building-microgrid.lbl.gov/projects/der-cam</a>	
3.	DistrictECA	Free for non-commercial use Requires Excel for output .csv files	Standalone Application	<a href="https://district-eca.com/index.php?lang=en">https://district-eca.com/index.php?lang=en</a>	
4.	DHAT	Free	Excel (no macro)	<a href="https://ens.dk/en/our-responsibilities/global-cooperation/district-heating-assessment-tool-dhat">https://ens.dk/en/our-responsibilities/global-cooperation/district-heating-assessment-tool-dhat</a>	
5.	EnergyLogic	Requires consulting contract w/ EDF	Standalone Application (AnyLogic)	Available only on project by project basis	
6.	EnergyPRO	DEMO mode is free; licenses start at <b>€3600</b> ; New users can often get a one-month trial	Standalone Application	<a href="https://www.emd.dk/energypro/">https://www.emd.dk/energypro/</a>	Can set up a model in DEMO mode, but cannot save file
7.	EOS	Requires a license	Standalone Application	Not yet released	Not yet released
8.	ETEM	Free	Standalone Application	<a href="http://www.ordecysys.com/en/etem">http://www.ordecysys.com/en/etem</a>	

9.	HOMER	Browser-based version is free. License required for standalone version	Browser-based app and Standalone Application	<a href="https://www.homerenergy.com/">https://www.homerenergy.com/</a>	
10.	NetSim	Requires a license	Standalone Application	<a href="https://www.vitecsoftware.com/en/products/areas/energy/products/netsim-grid-simulation/">https://www.vitecsoftware.com/en/products/areas/energy/products/netsim-grid-simulation/</a>	
11.	Plan4DE	Free; requires Excel	Excel macro	<a href="http://plan4de.ssg.coop/">http://plan4de.ssg.coop/</a>	Three different difficulty levels, each with increasing customization available
12.	RETScreen Expert	View mode is free <b>\$869/year</b> for 10 seats on software	Standalone Application	<a href="http://www.nrcan.gc.ca/energy/software-tools/7465">http://www.nrcan.gc.ca/energy/software-tools/7465</a>	Currently beta testing district energy software
13.	RETScreen Suite	Free Requires Excel	Standalone Application and Excel macro	<a href="https://nrcaniets.blob.core.windows.net/iets/RETScreenSuite.exe">https://nrcaniets.blob.core.windows.net/iets/RETScreenSuite.exe</a>	RETScreen 4 = Excel macro; RETScreen Plus = Application



## 2.2 Tool Benchmarking and Selection

Given the objectives and target audience of this report, tools were benchmarked based on the following criteria: Ease of Use; Maintenance, Updates, and Developer Support; Support for District Energy / District Cooling; and North American/ United States Focused. A point system was developed using these criteria; the tools with the highest score were selected for further review.

### Criteria Development

#### i. Ease of Use

Ease of Use was defined as a function of time that a person would need to invest to learn the basics of the software tool, gather the necessary data, and build a simple model.

Easy = Under 6 hours	Medium = 6 to 20 hours	Complex = 20+ hours
2 points	1 point	0 points

#### ii. Maintenance, Updates, and Support

Given this report's emphasis on teaching the reader how to use a new tool, with the hope that they then use it for a project, developer support and regular software updates are considered essential for the successful adoption of said tool.

Yes = 2 points	No = 0 points
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#### iii. District Energy / District Heating and Cooling Support

For the purposes of this project, it is essential that the selected tool(s) support both district heating and district cooling systems. Some tools only support district heating, while others do not currently support district energy modeling, but will in the next year.

Does not support District Energy = 0 points	Only supports District Heating = 1 point	Supports both District Heating and Cooling = 2 points
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#### iv. North American Focus

The target audience of this report is planners and engineers in North America. Thus, software tools that cater to this audience are prioritized.

North American Focus = 1 point	Other Regional Focus = 0 points
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Table 3. below rank the assessment tools reviewed against each of these criteria and provides an overall benchmarking score.

Table 3: Summary of Tools Benchmarking

Name	Ease of Use [Easy, Medium, or Complex]	Maintenance, Updates, and Developer Support?	District Energy Modeling? [No, DH Only, DH/DC]?	North American / United States Focus	Total Score
CEPOM	Medium*	Yes	DH/DC	Yes	6
DER-CAM	Complex	Yes	DH/DC	Yes	5
DistrictECA	Easy	No	DH/DC	No	4
DHAT	Easy	No	DH Only	No	3
EnergyLogic	Medium*	Yes	DH/DC	No†	5
EnergyPRO	Medium	Yes	DH/DC	No†	5
EOS	Medium	Yes	DH/DC	Yes	6
ETEM	Complex	Yes	DH/DC	No	4
HOMER	Medium	Yes	No	Yes	4
NetSim	Complex	Yes	DH/DC	No	4
Plan4DE	Easy	No	DH Only	Yes	4
RETScreen Expert	Medium*	Yes	No**	Yes	4
RETScreen Suite	Medium*	Yes	DH/DC	Yes	6

\* Most of the software is straightforward, but some knowledge of HVAC equipment is required

† EnergyPRO is releasing a US version of their software in the next six months; EnergyLogic could be customized for US energy markets.

\*\* Will support district energy soon (in next six months)

## Key Findings

- CEPOM, EOS, and RETScreen Suite are currently available best tools for such assessment (i.e., tools with 6 points). Since EOS has not been released yet, only CEPOM and RETScreen Suite are further considered. Furthermore, CEPOM is currently awaiting the results of a licensing agreement. This leaves only one tool, RETScreen Suite, whose public access can be guaranteed.

- DER-CAM, EnergyLogic, and EnergyPRO scored 5 points. EnergyPro would be of greater interest when the US version of their software becomes available. DER-CAM tool is useful for optimal DER system sizing but requires detailed modeling and granular load/technologies information (which may not be readily available to municipality or campus energy planners). EnergyLogic is not publicly available; it is only available on a project by project basis. EDF R&D could provide a customized pre-feasibility assessment to interested stakeholders.
- The remaining tools will not be considered further at this time.
- No tool achieved a perfect score of 7 points. This demonstrates the need for an easy-to-use optimal tool to be created for the thermal microgrid assessment or need of enhancements in the existing tools.

The following section describes how the selected tools, RETScreen Suite and CEPOM can be used by planners and utilities. A discussion on energy efficiency improvements is also included. In Section 4, a vision for the optimal thermal microgrid planning tool is presented.

### CEPOM Overview

#### Capabilities

CEPOM is currently the most detailed assessment tool for thermal microgrids. Its ability to optimize system operation at the hourly level, given hourly inputs of all parameters, makes its CHC analysis as robust as enterprise software packages such as energyPRO. **Furthermore, the enterprise solution of CEPOM, EOS, should provide a more user-friendly interface when it is released.** As with RETScreen, consistent, accessible customer support was taken into consideration, as well as its focus on the United States and Canada, our target audiences.

#### Limitations

CEPOM in its current form (Excel Macro) is a bit intimidating upon first glance, as it contains over 50 Excel sheets. It also lacks graphics or menus for selecting different equipment. Entering different equipment is done implicitly when changing the efficiency parameters and storage capacities, as well as the flow rates. This may not be intuitive for a planner or utility manager. Moreover, the estimation of hourly cooling and heating loads could be challenging without advanced metering and monitoring.

### RETScreen 4/Plus Overview

#### Capabilities

The older version of RETScreen, RETScreen 4, supports district heating and cooling systems. The software includes a database of pumps and other equipment, as well as parameters for various types of electricity production, such as PV panels and wind turbines. **It is important to note that the RETScreen Expert will also support district energy systems within the next year.** RETScreen has been used by hundreds of thousands of people, and as such has great online documentation, as well as accessible staff. This is very important, since the target audience may be new to the software.

#### Limitations

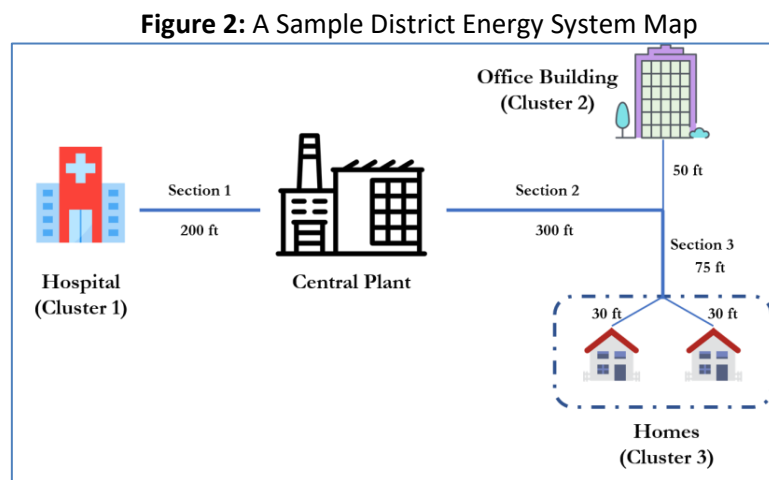
RETScreen 4 is less user-friendly than RETScreen Expert. The data is limited to monthly loads, which makes planning for peak loads more difficult. However, the software allows the user to specify a peak load heating system and cooling system and automatically calculates peak heating and cooling loads. These estimated peaks may be off from the actual observed system peak with granular data

availability. RETScreen 4 is also not equipped to model thermal storage along with combine heating and cooling.

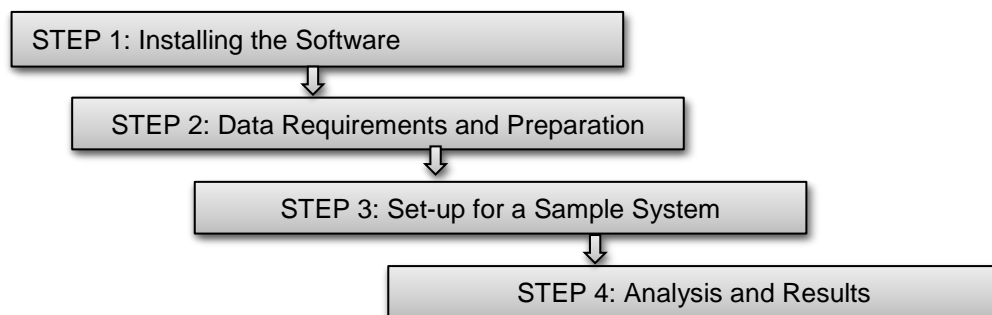
### 3 Step-by-Step Guide to Carry out a Municipal Feasibility Assessment

This section lays out the step-by-step process for modeling a sample thermal microgrid using RETScreen and CEPOM tools. Users may try other easy to use tools such as Plan4DE as a warm-up exercise for examining district energy potential.

For explaining the step-by-step process, we have considered a sample system district map as shown in **Figure 2**. This system is considered to provide a tangible example for the user to follow and does not necessarily represent an optimal choice for considering a thermal microgrid design.



In the following sections, detailed step-by-step guide for RETScreen and CEPOM tools are discussed. The guide follows the following high-level steps (1 - 4) to perform a pre-feasibility assessment:



#### 3.1 Performing a Pre-Feasibility Study Using RETScreen Suite

RETScreen is optimal for performing a pre-feasibility assessment of a new district energy system compared to the business-as-usual scenario. It provides cost, emissions, and financial estimates for both district heating and cooling. However, RETScreen does not have storage modeling capabilities.

## STEP 1: Installing RETScreen Suite

RETScreen Suite can be downloaded by selecting the link in the footnote<sup>10</sup>. The RETScreen Suite consists of RETScreen Plus and RETScreen 4. In the help manual, they are described as shown below.

- **RETScreen 4** is an Excel-based clean energy project analysis software tool that helps decision makers quickly and inexpensively determine the technical and financial viability of proposed renewable energy, energy efficiency, and cogeneration projects.
- **RETScreen Plus** is a Windows-based energy management software tool that allows project owners to easily verify the ongoing energy performance of their facilities.

Since the goal of this guide is to assess a new project, we will focus on RETScreen 4.

## STEP 2: Data Requirements and Preparation

The following table describes the required inputs to RETScreen 4. Most of these values should be readily available to facility managers. If some of the values are not initially known, the user can input the values from the RETScreen benchmark database. The part 4 of the project describes how this process was completed for two sites in Palo Alto, with a focus on the accurate calculation of the heating and cooling load per square meter of building area.

**Table 4:** Required data inputs into RETScreen4

Parameter	Units	Notes
Building Area	$m^2$ or $ft^2$	Can input different areas for heating and cooling
Distance Between Building Clusters	$m$ or $ft$	Used when calculating pipe lengths
Approximate heating load for each cluster	$W/m^2$ or $Btu/hr/ft^2$	If heating load is not known, the user can estimate load using the chart in RETScreen Manual (also shown in Appendix D)
Approximate cooling load for each cluster	$W/m^2$ or $Btu/hr/ft^2$ or $ft^2/RT$	If cooling load is not known, the user can estimate load using the chart in RETScreen Manual (also shown in Appendix D)
Existing heating fuel type	---	Usually natural gas
Existing cooling fuel type	---	Usually electricity
Existing system heating efficiency	---	Varies depending on the furnace, boiler type, age. Typically <b>70-90%</b>
Existing system cooling efficiency	---	Also called coefficient of performance (COP). Typical value for electric air conditioning = <b>3.0</b>
Fuel Rate	<i>varies</i>	Cost per unit of fuel

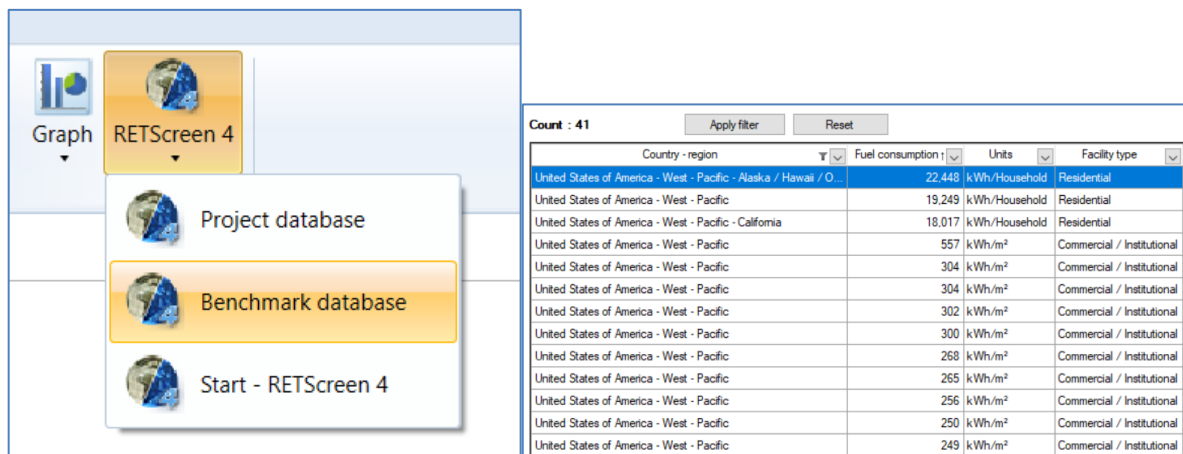
<sup>10</sup> <https://nrcan.ets.blob.core.windows.net/ets/RETScreenSuite.exe>

Pipe section lengths	<i>m or ft</i>	Determined by knowing building cluster spacing, distances between buildings within the cluster
DH/DC Supply Temps	<i>°F or °C</i>	temperature of hot and cold supply water
DH/DC Return Temps	<i>°F or °C</i>	temperature of hot and cold return water
Network Topology	---	Which pipe sections connect to which buildings
Various Costs	\$	Equipment costs, electricity costs, natural gas costs, O&M Costs, other misc. costs; other currency units available
Emission Factor	<i>Metric tons CO<sub>2</sub> per MWh</i>	Emissions associated with grid electricity. Ex: California = approx. 0.238 metric ton per MWh <sup>11</sup>
Financial Parameters	---	Project length, inflation, debt ratio, etc.

### Estimating Data

RETScreen contains a built-in database of building benchmark data. To access this database, open RETScreen Plus, select the RETScreen 4 dropdown menu, and select Benchmark Database. Data can be filtered by region, fuel type, units, facility type, and reference source. For other rough estimates of loads, databases such as the Electric Power Research Institution's (EPRI) Load Shape Library can be utilized<sup>12</sup>. Part 4 of the project has a more thorough discussion of data estimation techniques.

**Figure 3:** RETScreen4 tool screenshot for database benchmark



RETScreen also maintains a help manual, which can be accessed at any time by selecting *Help* under the *RETScreen* tab on the top navigation bar in Excel. Links to the Product Database, Climate Database, Hydrology Database, Project Database, and Benchmark Database can also be found here.

<sup>11</sup> <https://www.pge.com/includes/docs/pdfs/about/environment/calculator/assumptions.pdf>

<sup>12</sup> <http://loadshape.epri.com/wholepremise>

## STEP 3: Setup of a District Heating and Cooling System

- **Step 3.a. Set-up of *Cover Page*:** Once RETScreen Suite is installed, open RETScreen 4. This will open a new Excel file. On the *Start* sheet, enter the project information, select *Combined Heating & Cooling* under project type, and select *show settings* and change to imperial units. Finally, click *select climate data location*, enter the address of interest, and select the green check mark to apply changes. After entering the data, the sheet should appear as follows. RETScreen will automatically find the weather data from the station closest to the selected address. Screenshot of this step is shown in **Figure 4**

**Figure 4:** RETScreen4 cover page screenshot (Step 3.a)

Project information		<a href="#">See project database</a>
Project name	Demo Project	
Project location	Palo Alto, CA	
Prepared for	The Audience	
Prepared by	Robert Spragg	
Project type	Combined heating & cooling	
Analysis type	Method 1	
Heating value reference	Higher heating value (HHV)	
Show settings	<input checked="" type="checkbox"/>	
Language - Langue	English - Anglais	
User manual	English - Anglais	
Currency	\$	
Units	Imperial units	
Site reference conditions		<a href="#">Select climate data location</a>
Climate data location	Mountain View Moffett Fld	
Show data	<input type="checkbox"/>	

- **Step 3.b. Set-up for the *Load & Network* sheet:** On this sheet, the first step is to fill out the Base Case (or business-as-usual) heating system. Since we are modeling a system with multiple buildings, select *multiple buildings - space heating*. We will be modeling multiple clusters of buildings. Each cluster can contain multiple buildings, but all buildings within a cluster should be the same type<sup>13</sup>. We will be modeling the sample system with 3 clusters as shown in Figure 2.

- **Step 3.b.1: Entering Heating Data – Base Case (or *business-as-usual* BAU)**

Start by entering the total heated floor area for each building cluster in the *base case heating system* section. At first, only one building cluster will have a number entered. Placing values in the gray boxes for additional clusters generates new clusters. Once three clusters have been created, enter the number of buildings in each one (1,1,2 for the sample system (Figure 2)). Enter a value for their seasonal efficiencies. Typical heating system efficiency values are presented by the US Department of Energy<sup>14</sup>. Next, enter the heating load (W/m<sup>2</sup> or Btu/hr/ft<sup>2</sup>) for each cluster, and enter the percentage of the total heating load that is for hot water. These values could be estimated with the help of analyzing past utility bills and seeking information from facility managers on floor area. Appendix D

<sup>13</sup> While this is ideal, it is not critical for all buildings within a cluster to have similar loads. In the part 4 report, clusters were determined by street, not building type.

<sup>14</sup> <https://www.energy.gov/energysaver/home-heating-systems/furnaces-and-boilers>



discusses this in detail. Other ways to estimate end-use ratios include using state or federal survey data<sup>15,16</sup>. Finally, enter the cost of natural gas for each cluster, adjusting units as needed.

Under *Proposed Case Energy Efficiency Measures*, the user can specify a percentage reduction in energy use for each cluster for the new district energy system. Note that this only involves changes that occur separately from the new system, such as replacing windows or insulation. Now that the base case and proposed improvements have been input, the sheet should appear as shown in Figure 5. (numbers and units can vary as desired).

**Figure 5:** RETScreen4 screenshot; Load & Network sheet, BAU heating data (Step 3.b.1)

Heating project		Unit					
Base case heating system		Multiple buildings - space heating			Building clusters		
<a href="#">See technical note on heating network design</a>							
Heated floor area per building cluster	ft <sup>2</sup>	90,000		1	2	3	
Number of buildings in building cluster	building	4		40,000	45,000	5,000	
Fuel type				1	1	2	
Seasonal efficiency	%	-		Natural gas - therm	Natural gas - therm	Natural gas - therm	
Heating load calculation				75%	75%	75%	
Heating load for building cluster	W/m <sup>2</sup>	-		50	50	50	
Domestic hot water heating base demand	%	20%					
Total heating	million Btu	2,715		1,207	1,358	151	
Total peak heating load	million Btu/h	1		1	1	0	
Fuel consumption - unit		-		therm	therm	therm	
Fuel consumption - annual		-		16,091	18,103	2,011	
Fuel rate - unit		-		\$/therm	\$/therm	\$/therm	
Fuel rate		-		1.100	1.200	1.350	
Fuel cost	\$	42,139		\$ 17,700	\$ 21,723	\$ 2,715	
Proposed case energy efficiency measures							
End-use energy efficiency measures	%	0%		0%	0%	0%	
Net peak heating load	million Btu/h	1		1	1	0	
Net heating	million Btu	2,715		1,207	1,358	151	

▪ **Step 3.b.2: Entering Heating Data – Proposed Case (or new energy system)**

Next, the user should fill in the *Proposed Case District Heating Network* section. Start by entering the hot water supply and return temperatures. Typical supply and return values are 80 and 50 degrees Celsius (or 176 and 122 °F)<sup>17</sup>, respectively. Enter a percentage for network oversizing, to account for any future expectations of heat load growth.

Afterwards, one must define the pipe network. We have estimated primary and secondary pipe lengths in the sample system map (Figure 2). The pipes labeled as Sections are the main distribution lines. The other lines are called secondary distribution lines (only shown for Clusters 2 and 3). Enter the section lengths (200', 300', 75' for the sample system) into the length column. Next, specify which sections support which clusters. In our sample system figure, Section 1 supports only Cluster 1. Section 2 supports Clusters 2 and 3, and Section 3 supports Cluster 3. **The software will automatically calculate the load and pipe size for each section.** Next, specify the length of secondary distribution pipes. Cluster 1 has no secondary pipe, Cluster 2 has 50' and Cluster 3 has 60' (two 30' sections). Finally,

<sup>15</sup> <http://www.energy.ca.gov/2006publications/CEC-400-2006-005/CEC-400-2006-005.PDF>

<sup>16</sup> <https://www.eia.gov/consumption/residential/>

<sup>17</sup> Stanford's system has hot water supply and return temperatures of 165 and 130°F, respectively. <https://sustainable.stanford.edu/sesi/innovation>

enter 2.00 for the three cost factors and the appropriate exchange rate<sup>18</sup>. RETScreen will automatically calculate the total heating network cost, as well as an itemized cost breakdown.

**Figure 6:** RETScreen4 screenshot; Load & Network sheet, new heating system data (Step 3.b.2)

Proposed case district heating network		Estimate/Total	
<b>Heating pipe design criteria</b>			
Design supply temperature	°C	80	
Design return temperature	°C	50	
Differential temperature	°F	54	
<b>Main heating distribution line</b>			
Main pipe network oversizing	%	20%	
<b>Pipe sections</b>	Load million Btu/h	Length ft	Pipe size mm
Section 1	1.4	200	DN 80
Section 2	2.1	300	DN 100
Section 3	0.2	75	DN 40
Section 4			
<b>Is the building cluster supplied by this pipe section? (yes/no)</b>			
		1	2
		Yes	No
		No	Yes
		No	No
		No	Yes

Secondary heating distribution lines		Secondary distribution pipes length per building cluster				
Secondary pipe network oversizing	%	0%				
Length of pipe section	ft	110	ft	0	50	60
Pipe size	mm		DN 50	DN 65	DN 32	
<b>District heating network cost</b>						
Total pipe length	ft	685				
Costing method		Formula				
Energy transfer station(s) connection type		Direct				
Energy transfer station(s) cost factor		2.00				
Main distribution line pipe cost factor		2.00				
Secondary distribution line pipe cost factor		2.00				
Exchange rate	\$/CAD	0.76				
<b>ETS and secondary distribution pipes costs per building cluster</b>						
Energy transfer station(s) cost	\$	95,490	\$	42,840	\$	45,978
Secondary distribution line pipe cost	\$	16,975	\$	-	\$	8,817
Total building cluster connection cost	\$	112,465	\$	42,840	\$	54,794
			\$		\$	14,830
<b>Main distribution line pipe cost by pipe size categories</b>						
Summary of main distribution line pipe size	mm	DN 32	DN 40	DN 50	DN 65	
Summary of main distribution line pipe length	ft	75	-	-	500	
Summary of main distribution line pipe cost	\$	10,198	-	-	88,165	
Total district heating network cost		\$	210,828			

- **Step 3.b.3: Entering Cooling Data – Base Case (or *business-as-usual* BAU)**

Select *multiple buildings - space cooling* as the base case cooling system. As with the heating section, enter the floor area for each cluster. This can sometimes be different than the heated floor area of the same building. Next, enter the coefficient of performance for each cluster. Typical electric air conditioners have a COP of 2 to 4; enter 2.6 to be conservative<sup>19</sup>. Afterwards, enter the cooling load for the building cluster, using the units of your choice, as well as the percentage of non-weather dependent cooling. If unknown, typical values for cooling loads can be found in Appendix C<sup>20</sup>. **The total cooling and cooling peak load will be generated automatically.** The units of RT stand for tons of refrigeration.

Next, in the *fuel rate* row, enter the average \$/kWh that each building cluster pays for electricity. If the cluster is on a time-of-use plan, an average rate should be approximated from past bills. Finally, enter the energy efficiency measures that will be undertaken that are unrelated to the district cooling network, such as

<sup>18</sup> For example, enter 0.76 if using USD: accurate as of September 2018. Cost factors will vary depending on location. Values of 2.00 were used in the part 4 report, to account for the higher-than-average construction costs in Palo Alto.

<sup>19</sup> <http://www.powerknot.com/2011/03/01/cops-eers-and-seers/>

<sup>20</sup> These values are estimated by considering the heating and cooling design temperature for a given location

installing shades or installing dual-pane windows. At this point, the base case cooling system should appear as shown in Figure 7.

**Figure 7:** RETScreen4 screenshot; Load & Network sheet, BAU cooling data (Step 3.b.3)

Cooling project	Unit				
Base case cooling system			Building clusters		
Multiple buildings - space cooling			1	2	3
<a href="#">See technical note on cooling network design</a>			30,000	40,000	5,000
Cooled floor area per building cluster	ft²	75,000	1	1	2
Number of buildings in building cluster	building	4	Electricity	Electricity	Electricity
Fuel type		-	2.60	2.60	2.60
Coefficient of performance - seasonal		-			
Cooling load calculation			30	30	30
Cooling load for building cluster	W/m²	-	68,721	91,628	11,454
Non-weather dependant cooling	%	10%	24	32	4
Total cooling	RTh	171,803	MWh	MWh	MWh
Total peak cooling load	RT	59	93	124	15
Fuel consumption - unit		-	\$/kWh	\$/kWh	\$/kWh
Fuel consumption - annual		-	0.130	0.170	0.200
Fuel rate - unit		-			
Fuel rate		-	\$	\$	\$
Fuel cost	\$	36,252	12,084	21,070	3,098
Proposed case energy efficiency measures			0%	0%	0%
End-use energy efficiency measures	%	0.0%	24	32	4
Net peak cooling load	RT	59	68,721	91,628	11,454
Net cooling	RTh	171,803			

▪ **Step 3.b.4: Entering Cooling Data – Proposed Case (or new energy system)**

Next, we will enter the district cooling data. Select supply and return temperatures around 5 and 10 Celsius<sup>21</sup> (or 41 and 50 °F)<sup>22</sup>, respectively, and an oversizing of 10% to account for any future load growth. Next, enter the same pipe section configuration as the heating loads (Section one is 200' and supplies Cluster 1, etc.). Repeat for the secondary distribution network.

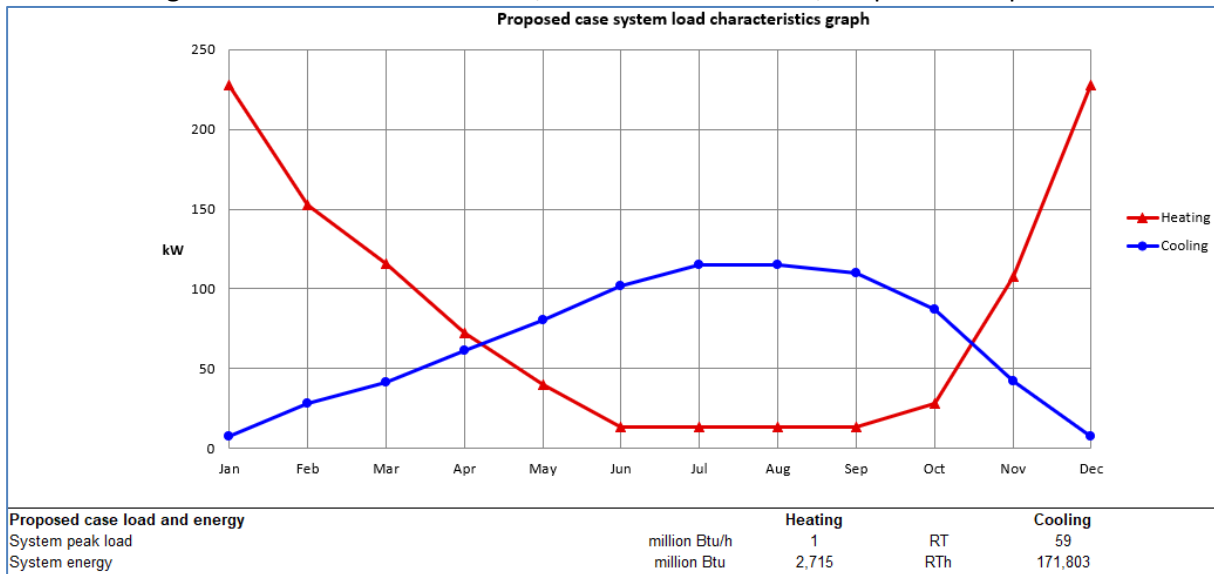
As with the heating network, the total district cooling cost, broken down into station costs, main distribution line costs, and secondary distribution costs, are automatically calculated.

### Graphical Interpretation

At the bottom of the RETScreen 4 Load & Network Sheet, two plots, showing the base case and proposed case, are automatically generated (as shown in Figure 8). For the proposed (district energy) case, the peak load and system energy are presented. The resolution of the outputs is monthly.

<sup>21</sup> <https://www.districtenergy.org/HigherLogic/System/DownloadDocumentFile.ashx?DocumentFileKey=eac74754-05c9-a7cc-cede-0261984fa8e7>, Slide 21/33

<sup>22</sup> Stanford's SESI facility has cooling supply and return temps of 42 and 58°F, respectively.

**Figure 8:** RETScreen4 screenshot; Load & Network sheet, Graphical Interpretation

Now that the Load & Network tab is complete, save the file and continue to the Energy Model sheet.

- **Step 3.c. Set-up for the *Energy Model* sheet:** The energy model tab asks the user to define specific parameters of the district heating and cooling system. It then performs an **emissions analysis** and a **financial analysis**. The energy model tab requires knowledge of cost and performance information for heat pumps and heating system equipment. For information about the different products available, select the product database link on the right-hand side. One can then search by technology, manufacturer, and more specific technology characteristics.

**Note:** For the Palo Alto studies, equipment costs were estimated on a per-unit of capacity basis, using data from Stanford's Redwood City campus project. These per-unit costs, as well as alternative cost estimates provided by RETScreen, are shown in Appendix B. A subset is shown below.

- Chiller: \$400 per ton
- Hot Water Generator: \$50 per MBH

- **Step 3.c.1. Entering Cooling Equipment Info – Proposed Case (or new energy system):** For this analysis, we will assume that our base load cooling system is an electric air-source heat pump. For a graphical interpretation of base load versus peak load cooling systems, see Appendix C. Select *see product database* and choose a heat pump. Click the green check mark to auto-fill the heat pump's parameters into the capacity, manufacturer, and model tabs. **Cost data must be entered manually.** Next, assume that the peak load cooling system is an electric compressor<sup>23</sup>. Again, select the corresponding *see product database* link to select a compressor. If the selected product's capacity does not exceed RETScreen's suggested capacity, the model will state that peak load is not met in red font. Once

<sup>23</sup> **Note:** Stanford's SESI system does not have a cooling peak load; there are only regular chillers and heat recovery chillers

the base and peak load systems are selected, the sheet should appear as follows (Figure 9).

### Equipment Cost Estimation

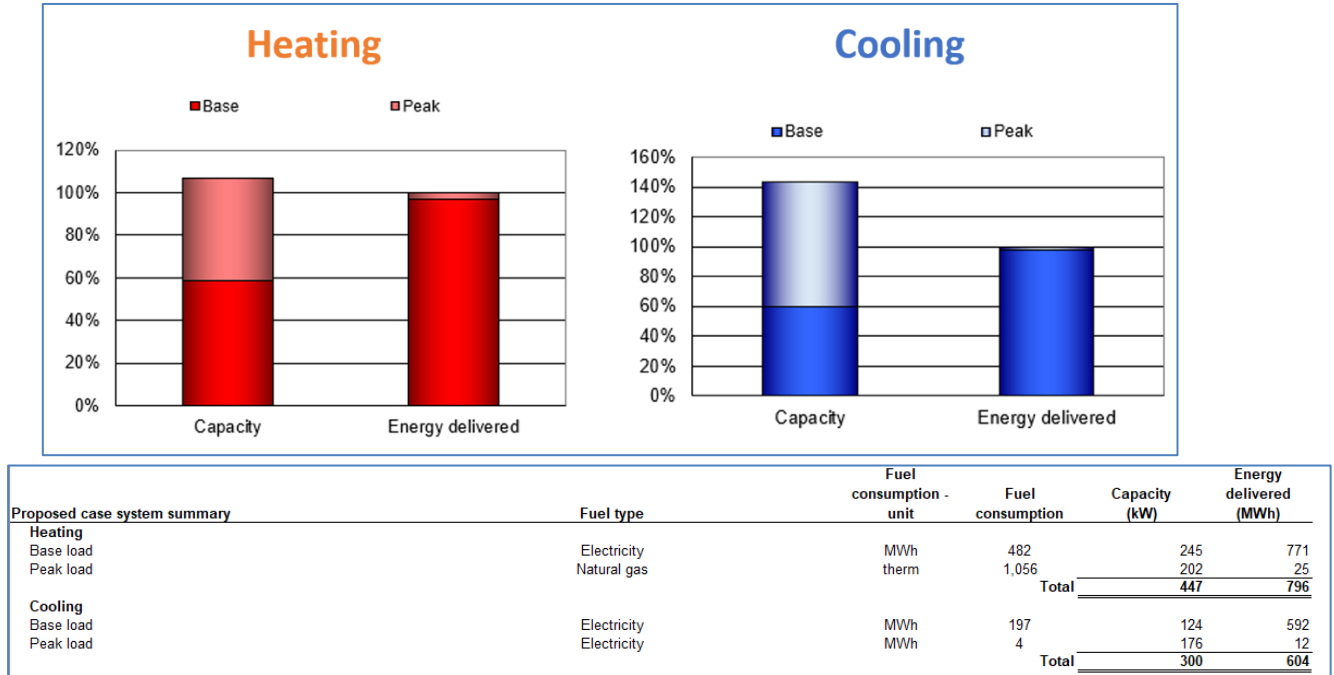
- Electric Heat Pump (chilling base load):  $35.4 \text{ tons} * \frac{\$400}{\text{ton}} = \$14,160$
- Electric Compressor (chilling peak load):  $50 \text{ tons} * \frac{\$400}{\text{ton}} = \$20,000$
- Electric Heat Pump (heating base load; ideally a Heat Recovery Chiller):  $245 \text{ kW} * 0.284 \frac{\text{ton}}{\text{kW}} * \frac{\$600}{\text{ton}} = \$41,748$
- Natural Gas Boiler (heating peak load):  $0.69 \frac{\text{mmbtu}}{\text{hr}} * \frac{1000 \text{ MBH}}{\text{mmbtu}} * \frac{\$50}{\text{MBH}} = \$34,500$

**Figure 9:** RETScreen4 screenshot; Energy Model sheet, proposed cooling system (Step 3.c.1)

Proposed case cooling system				Incremental initial costs
<b>Base load cooling system</b>				
Technology	Heat pump			
Fuel type	Electricity			
Fuel rate	\$/MWh	100.000		
Capacity	RT	35.4	59.6%	\$ 18,880
Coefficient of performance - seasonal		3.00		
Manufacturer	Lennox			
Model	THA150S2B			3 unit(s)
Cooling delivered	RTh	168,366	98.0%	
<b>Peak load cooling system</b>				
Technology	Compressor			
Fuel type	Electricity			
Fuel rate	\$/MWh	100.000		
Suggested capacity	RT	24.0		
Capacity	RT	50.0	84.1%	\$ 78,000
Coefficient of performance - seasonal		3.00		
Manufacturer	York International			
Model	YTJ -A			1 unit(s)
Cooling delivered	RTh	3,437	2.0%	

- **Step 3.c.2. Entering Heating Equipment Info – Proposed Case (or new energy system):** Move to the *proposed case heating system* section. Select heat pump as the technology, and electricity as the fuel type. Next, select a heat pump device. For the system characteristics section, the peak load heating system must also be defined. We will assume that peak loads are handled by a natural gas boiler. Stanford's SESI system also uses natural gas for peak heating loads. The user can also define optional back-up heating and cooling systems.

Once the three proposed case system sections are completed, RETScreen generates graphs that show the system capacity versus actual demand, and the energy delivered by the heating and cooling base and peak load systems. If the equipment capacity is sufficient, the *capacity* quantity will be larger than the *energy delivered* quantity.

**Figure 10:** RETScreen4 screenshot; Energy Model sheet, proposed case system summary

## STEP 4: Analysis and Results

**Emissions Analysis:** The emissions analysis helps the user understand the GHG emission reductions that the proposed district energy system can provide. To perform this analysis, the emissions from the existing electricity grid must be quantified. Since we are using electricity for heating and cooling water in this example, the location selected will play a large role in the emissions reductions. For the sample district energy system, we have selected Guatemala as the country and all types of fuel for electricity generation. Transmission and distribution (T&D) losses are estimated to be 1%. A credit rate (\$/tCO<sub>2</sub>) can also be entered; this is equivalent to a carbon tax or carbon allowance price. In a scenario with no carbon tax or carbon price, the table might appear as follows (Figure 11). Guatemala was selected because it had an emissions factor similar to CA<sup>24</sup>.

**Figure 11:** RETScreen4 screenshot; Energy Model sheet, Emissions Analysis

Emission Analysis					
Base case electricity system (Baseline)					
Country - region	Fuel type	GHG emission factor (excl. T&D) tCO <sub>2</sub> /MWh	T&D losses %	GHG emission factor tCO <sub>2</sub> /MWh	
Guatemala	All types	0.286	1.0%	0.289	
<b>GHG emission</b>					
Base case	tCO <sub>2</sub>	257.0			
Proposed case	tCO <sub>2</sub>	202.7			
Gross annual GHG emission reduction	tCO <sub>2</sub>	54.3			
GHG credits transaction fee	%	2.0%			
Net annual GHG emission reduction	tCO <sub>2</sub>	53.2	is equivalent to	9.7	Cars & light trucks not used
<b>GHG reduction income</b>					
GHG reduction credit rate	\$/tCO <sub>2</sub>	0.00			

- **Financial Analysis:** The financial analysis section allows the user to assess the feasibility of their proposed district heating system. The following inputs are required:
  - Inflation rate
  - Project lifespan (typically 20 or 50 years)
  - Debt ratio

<sup>24</sup> <https://www.pge.com/includes/docs/pdfs/about/environment/calculator/assumptions.pdf>

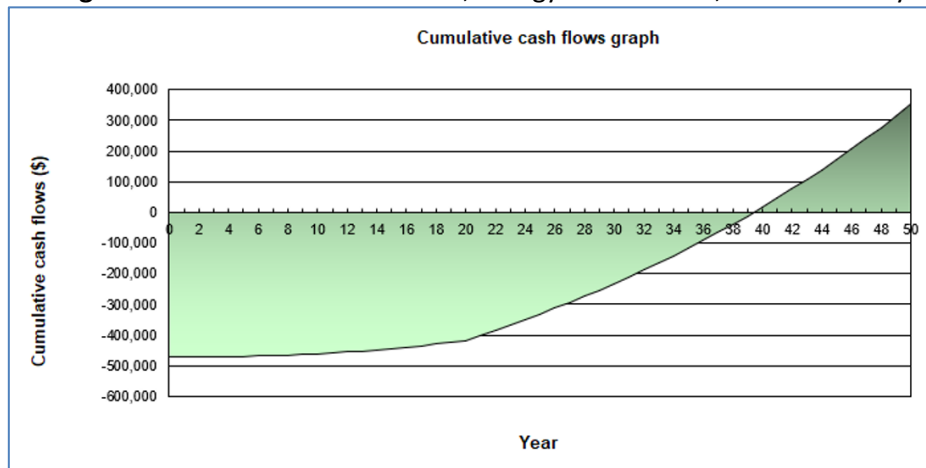
- Debt interest rate
- Debt term
- O&M (savings) costs (enter a negative number for savings)

The following outputs are calculated:

- Pre-tax IRR - equity (%)
- Pre-tax IRR - assets (%)
- Simple Payback (years)
- Equity Payback (years)

A graph is also generated which helps visualize the cash flow resulting from the project (Figure 12). The **Figure 12** cash flow graph just provides as an illustration and does not represent a realistic financial scenario. In a real case study, the cash flow analysis will be highly sensitive to the inflation rate and project lifespan.

**Figure 12:** RETScreen4 screenshot; Energy Model sheet, Financial Analysis



## Summary

The RETScreen 4 Excel program allows the user to perform a Pre-Feasibility study, which is typically done to determine whether a more detailed feasibility study or engineering design is practical. According to a RETScreen engineer, analyzing monthly data is usually adequate for making this decision<sup>25</sup>. If further work is deemed necessary, assessments using the following tool can be performed. The current configuration of the RETScreen does not allow for thermal energy storage modeling and capturing of simultaneous heating and cooling loads at an hourly resolution. Therefore, in Section 3.2 we discuss the application of the CEPOM tool for assessing a thermal microgrid at an hourly resolution.

## 3.2 Performing a Feasibility Study Using CEPOM

Using CEPOM is optimal for planning a new combined heating-cooling (CHC) facility, once the participating buildings have been identified and consumption data has been generated for electricity, cooling, and heating loads at an hourly resolution for a year. Gathering thermal energy data at an hourly level requires some advance system metering and monitoring. We are looking into solutions to

<sup>25</sup> Email correspondence with Kevin Bourque, Project Engineer, RETScreen

estimate hourly load data using city-level hourly energy consumption and typical equipment operating schedules.

## STEP 1: Installing the Software

- CEPOM is an excel based tool and does not require a separate installation. Stanford has made CEPOM available in the past for non-commercial use. However, currently, Stanford is in negotiations with Johnson Controls to develop an enterprise software based on CEPOM (EOS). The public availability of the software is contingent on the pending legal negotiations.

## STEP 2: Data Requirements and Preparation

- The following table maps the Excel sheets within CEPOM to the required data. Many data entries require 8760 data (i.e., hourly data for a year in the form of a 365 by 24 matrix; 365 days in a year and 24 hours in a day). Whenever an 8760 is required, the rows represent the days of the year, and the columns represent the hour of the day. The 8760 information may not be readily available and may require advanced metering and monitoring of the buildings and total system energy usage.

**Table 5: CEPOM Data Input Sheet Explanation**

Input Data Sheet Name	Required Data	Units	Notes
CampusKWH	8760 of total electricity loads	kWh	
CW Loads	8760 of cold water loads	tons	
HW Loads	8760 of hot water loads	MMBtu	
Outside Air Temp (Dry Bulb)	8760 of dry bulb temp	° F	
Outside Air Temp (Wet Bulb)	8760 of wet bulb temp	° F	
Electricity Rates	8760 of rates	\$/kWh	
Demand Rates	8760 of demand charge	\$/kW	Peak Demand Charge
Gas Rates	8760 of gas rate	\$/MMBtu	
HRC1CAP	8760 for capacity of first heat pump	tons	Values should be constant; specific times can be modified to reflect maintenance
HRC2CAP	“ “ second heat pump		Values can be set to zero for initial system sizing
HRC3CAP	“ “ third heat pump		Values can be set to zero for initial system sizing



C6CAP	8760 for cold storage capacity	tons	Values should be constant; specific times can be modified to reflect maintenance
C7CAP	“ “		Values can be set to zero for initial system sizing
C8CAP	“ “		Values can be set to zero for initial system sizing
C9CAP	“ “		Values can be set to zero for initial system sizing
H1CAP	8760 for hot water storage	MMBtu	Values should be constant; specific times can be modified to reflect maintenance
H2CAP	“ “ second storage tank		Values can be set to zero for initial system sizing
H3CAP	“ “ third storage tank		Values can be set to zero for initial system sizing
H1ePE	Electricity use of hot water generator	kWh/ MMBtu	For fans, etc.
H2ePE			Will not matter if H2CAP is zero
H3ePE			Will not matter if H3CAP is zero

### Data Conversion

If the user has cooling or heating loads in different units, the following conversion table can help with conversion to the CEPOM units.

**Table 6: Units used in CEPOM**

CEPOM Unit	CEPOM Use	Unit	Other Unit 1	Other Unit 2
Ton of Refrigeration (RT or TR) <sup>26</sup>	Chilled Water	Power	~12,000 BTU/hr	~3.5kW
MMBtu	Hot Water	Heat	~293 kWh	--

More tabs also exist, to support up to ten HRC systems (#1-10), nine chillers (#6-10), and five hot water heaters (#1-10).

## STEP 3: Setup of a Thermal Microgrid System

- **Step 3.1. Data Entry into CEPOM:** In CEPOM, sheets with yellow tabs are sheets where data entry is allowed. In the demo version used for this report, **orange cells** within these sheets

<sup>26</sup> [https://en.wikipedia.org/wiki/Ton\\_of\\_refrigeration](https://en.wikipedia.org/wiki/Ton_of_refrigeration)

represent cells where the user must enter their own data. When using CEPOM for the first time, it is likely that the number of heat recovery chillers, chillers, and hot water tanks has not been determined. Therefore, when running the model, the user should focus first on finding the total required capacity, and then identify the capacity and quantity of individual system elements during subsequent model runs. For this demo, the quantity of devices will remain the same as what exists currently at Stanford (3 Heat Recovery Chillers, 4 Chillers, 3 Hot Water Heaters).

- **Step 3.2. Entering Electricity, Cold Water, and Hot Water Demand:** Next, the hourly electricity data should be input into CEPOM. The data should be organized such that each row and column correspond to a day and hour, respectively. An example fragment of the datasheet is shown in **Figure 13**. The easiest way to import data into each sheet is to paste it from another Excel file. Sample Excel sheets for all necessary data, in the correct format, can be found online<sup>27</sup>. The user could utilize this sample data for the purposes of this guide.<sup>28</sup>

**Figure 13:** CEPOM screenshot; 8760 electricity data entry

	1,727,433	1.065392			
kwh					
	0:00	1:00	2:00	3:00	4:00
Friday, January 1, 2016	121	121	122	128	136
Saturday, January 2, 2016	121	121	122	128	136
Sunday, January 3, 2016	121	121	122	128	136
Monday, January 4, 2016	121	121	122	128	136
Tuesday, January 5, 2016	121	121	122	128	136
Wednesday, January 6, 2016	121	121	122	128	136
Thursday, January 7, 2016	121	121	122	128	136
Friday, January 8, 2016	121	121	122	128	136
Saturday, January 9, 2016	121	121	122	128	136
Sunday, January 10, 2016	121	121	122	128	136
Monday, January 11, 2016	121	121	122	128	136
Tuesday, January 12, 2016	121	121	122	128	136
Wednesday, January 13, 2016	121	121	122	128	136

The system cold and hot water loads should be entered in the same manner as the electrical loads. The units for cold water demand are in tons (or ton-hr, since the time-series has 1-hour increments). The units for hot water demand are in MMBtu. This step is a relatively difficult part of the CEPOM data entry process, as cooling and heating loads for buildings are not readily available on an hourly basis. In part 4 of the project, we perform the hourly estimates of heating and cooling needs for clusters of buildings in downtown Palo Alto and a corporate campus. A summary of this process is shown below.

1. Identify the ratio of energy use by building type in the area of interest (i.e., 20% of electricity is used by residential, 40% by commercial, etc.)
2. Identify end-use ratios for each month for each building type (i.e., 25% of electricity consumed by residential buildings in September is used for cooling)

<sup>27</sup> Properly Formatted CEPOM Data can be found in the 'Demo Data' folder: [https://office365stanford-my.sharepoint.com/:f/g/personal/spragg\\_stanford\\_edu/EvPLcgM9251HkTILQKsjY3gBkeNnz3RiLm2xL5c6nmimHQ?e=op6hew](https://office365stanford-my.sharepoint.com/:f/g/personal/spragg_stanford_edu/EvPLcgM9251HkTILQKsjY3gBkeNnz3RiLm2xL5c6nmimHQ?e=op6hew)

<sup>28</sup> Note: When pasting data into CEPOM, make sure to paste as values, and not as an equation linking to another Excel file. This will also maintain the orange fill color on the relevant cells.

3. Using building type and end-use ratios, identify total monthly heating and cooling consumption for each building type
  4. Using publicly available **hourly** building energy and equipment modeling data (or hourly city-level load data), create hourly load ratios and map total monthly heating and cooling consumption to hourly consumption.<sup>29</sup>
- Step 3.3 Entering Temperature, Electricity, Gas Data: Continue the same process for the outside temperature, electricity rates, demand rates, and gas rate sheets. If any data is not known for every hour of the year, a representative 24-hour period could be determined for each month and repeated. Furthermore, electricity rates might be constant or only change twice per day, depending on the type of existing rate structure with the utility. Stanford's electricity rates vary hourly because Stanford qualified for Direct Access to the California electricity market in 2010<sup>30</sup>.
  - Step 3.4 Adjusting the Heat Recovery Chiller and Heating Efficiencies: The *HRC1PE-HRC3PE* tabs contain the efficiency value of the heat recovery chillers. The default value is 1.33 kW/ton and is constant for all hours. To be more conservative, an efficiency of **1.5 kW/ton**<sup>31</sup> (depending on cold water loop temperature) can be used. Finally, the *H1ePE-H3ePE* tabs define the electricity necessary to operate the natural gas hot water heater (fans, pumps, etc.). The default value is 2kWh/MMBtu.
  - Step 3.5 Adjusting the Central Energy Facility Energy Consumption: The background electricity usage by the Central Energy Plant building can be set in the *CEFBLDGKWH* sheet. For this demonstration, the model was set at 3.0 kW (26.3 MWh per year). The background consumption can be assumed to be proportional to the total heating and cooling load delivered on an annual basis<sup>32</sup>.

## STEP 4: Analysis and Results

- Step 4.1 Running the Model: Now that all of the parameters have been entered, return to the second sheet in CEPOM, titled *model*. The sheet should appear as follows (**Figure 14**). The user can change the storage capacities and initial conditions (storage balances). The maximum discharge and recharge rates are defined as functions of the storage capacities. **Before clicking Run 1 Year Model, make sure to save the model.** Also, make sure that *Calculation Options* is set to **manual**. Otherwise, the model will take very long to run. Once the file has saved, click the run button. The model run should take between **30 minutes to an hour**, depending on available memory and computer type. Once the model completes, save it again, to ensure that the summary table data is updated.

<sup>29</sup> For example, refer to Open Data Catalogue by DOE for hourly load profiles for commercial and residential buildings <https://openei.org/doe-opendata/dataset/commercial-and-residential-hourly-load-profiles-for-all-tmy3-locations-in-the-united-states>

<sup>30</sup> [http://sustainable.stanford.edu/sites/sustainable.stanford.edu/files/documents/FactSheet\\_FAQ\\_SESI.pdf](http://sustainable.stanford.edu/sites/sustainable.stanford.edu/files/documents/FactSheet_FAQ_SESI.pdf)

<sup>31</sup> Thermal Microgrid Whitepaper, pg. 23

<sup>32</sup> Correspondence with Joe Stagner; The Stanford facility produces approximately 1.5 million MMBtu of heating and cooling annually, and consumes an average of 250 kW.

**Figure 14:** CEPOM screenshot; model run tab

Central Energy Plant Optimization Model				
Fixed Model Inputs				
Year:	2016			
Month:	Jan		Maximum discharge rate	Maximum recharge rate
Day:	1			
Chilled Water Storage Capacity (ton-hr):	10,000		2,000	2,000
Hot Water Storage Capacity (mmbtu):	10		2	2
Starting Chilled Water Storage Balance (ton-hr):	10,000	<<< as of 7 am on start date		
Starting Hot Water Storage Balance (mmbtu):	10	<<< as of 7 am on start date		
HRC Cost Split to Chilled Water:	50%			
HRC Cost Split to Hot Water:	50%			
Maximum Allowable HV Peak Demand (kw):	50,000			
Minimum HRC physical turndown:	500			
Allow waste heat beyond CHP norm?	No			
Allow external electricity export?	No			
Give preference to CW heat recovery over CHP waste heat?	No			

- **Step 4.2 Results Interpretation:** The results sheets tabs are highlighted with dark blue. There are four results sheets; *Summary Results*, *Production Distribution - Month*, *Electricity Use - Season*, and *Electricity Use - Month*. Once the model has run, select the *Summary Results* sheet. The sheet is broken down into four color-coded sections: Thermal Energy, Electricity, Gas, and Overall Performance. Furthermore, at the bottom of the sheet, tables have been added that provide the approximate required thermal energy storage and equipment capacities, as well as the total heating and cooling cost and a sanity check of equipment efficiencies and electricity consumption. Table 7 provides a short description of each of these sections. The results from our trial run, using data provided in the Microsoft OneDrive folder, are shown in Figure 15).

**Table 7:** Description of *Summary Results* sections in CEPOM

Section	Description
Thermal Energy	Describes the total amount of hot and cold load provided by each device for heating and cooling. Also provides total cost, including a cost breakdown by device, for the CEF, and for distribution.
Electricity	Lists total energy use for each device type (HRCs, Chillers, Heaters), as well as by the Energy Plant, distribution system, and campus buildings. Provides associated electricity cost of each end use.
Gas	Describes total natural gas use and cost from hot water heaters. Natural gas is only used to handle peak heating loads in Stanford's system.
Overall Performance	Describes the total energy cost, CO2 emissions, water use, etc. CO2 emissions can be adjusted by varying the grid GHG factor. Trigeneration efficiency is a function of the assumed power grid efficiency.
Added Material	Lists the minimum required hot and cold water storage size, as well as required heat recovery chiller, hot water generator, and chiller capacities.

**Figure 15: CEPOM screenshot; Summary Results**

DEMO Central Energy Plant Optimization Model 2016																				
Summary Results (Energy Throughput and Cost)																				
Loads			Production									Energy Cost								
Loads	TES Change	Total	HRCs	Chillers	Heaters	CEP Bldg	Distribution	Campus Bldgs	GSHE	Unmet loads	Total	HRCs	Chillers	Heaters	CEP Bldg	Distribution	Campus Bldgs	Total		
Thermal Energy																				
Chilled Water (ton-hr)	463,093	0	463,093	436,262	26,831					0	463,093	\$ 39,165	\$ 1,586		\$ 1,779	\$ 5,001		\$	47,532	
Heat (mmbtu)	12,465	0	12,465	7,211		5,253				0	12,465	\$ 39,165		\$ 72,495	\$ 1,779	\$ 3,029		\$	116,468	
Electricity																				
Electricity Use & Cost (kWh)			580,229	11,751	10,507	26,352	59,484	1,727,433	0		2,415,755	\$ 78,331	\$ 1,586	\$ 1,418	\$ 3,558	\$ 8,030	\$ 233,203	\$	326,127	
Electricity Demand & Cost (kW)											963							\$	82,413	
Gas																				
Gas Used (mmbtu)					6,181						6,181			\$ 71,076				\$	71,076	
Overall Performance																				
Assumed Grid Power Efficiency 51%			Chilled Water to Heat Recovery 94%			Grid HV Load Factor			29%			Grid GHG factor (m-tons CO2/MWh)			0.27216			Total Energy Cost \$ 479,616		
Overall Trigeneration Efficiency w 100% Gas 108%			Hot Water from Heat Recovery & GSHE 88%			Water use (gallons)			31,943			Total Category I and II GHG (m-tons CO2)			985			Total Energy + Water Cost \$ 479,920		
Overall Trigeneration Efficiency w 33% RPS 143%																				

**Figure 16: CEPOM screenshot; Capacities and Costs from Summary Results**

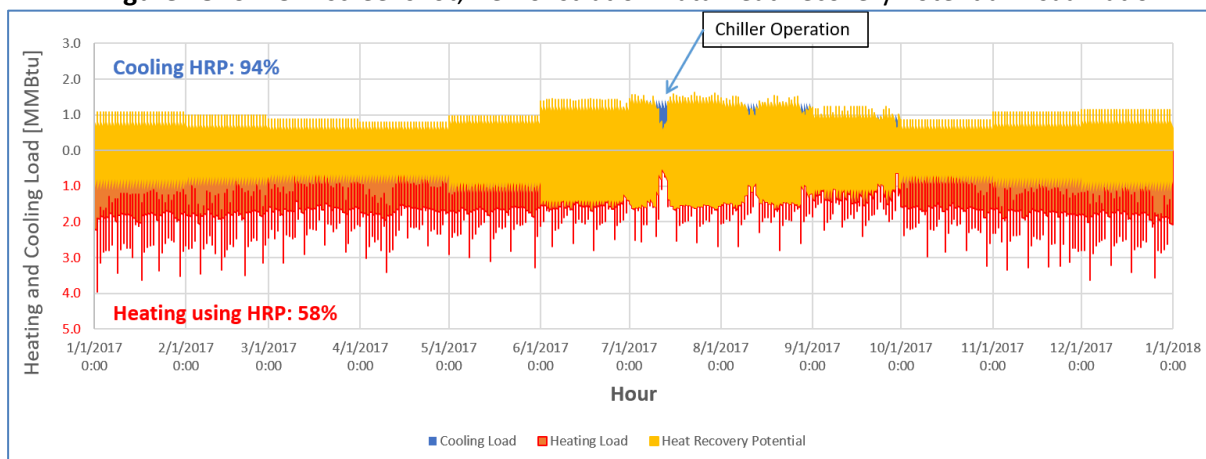
Minimum Allowable HW Storage	1.88 mmbtu	Total Heat Cost	\$ 116,468
Minimum Allowable CW Storage	1640 ton-hr	Total Cool Cost	\$ 47,532
Minimum Allowable HRC Cap	152 tons		
Minimum Allowable HW Gen Cap	4.16 mmbtu		
Minimum Allowable CW Gen Cap	1,636 tons		

In our example, almost all cold water (94%) is generated using the heat recovery chiller. This is because the demo heating loads are consistently equal to or higher than the cooling loads. This fact also explains why only 58% of the heat demand can be provided by the heat recovery chiller, with the remaining portion met using the natural gas hot water heater. The heat recovery potential for a given period can also be visualized, as shown in Figure 18.

**Figure 17:** CEPOM screenshot; *Summary Results*, Heat Recovery Potential



**Figure 18:** CEPOM screenshot; *Demonstration Data* Heat Recovery Potential Visualization



Within the Overall Performance section, the *Assumed Grid Power Efficiency* (or equivalent carbon footprint of the electricity supply) can be modified. The default value of 51% represents the efficiency of new natural gas-fired combined cycle power plant<sup>33</sup>. The grid GHG factor can also be modified, depending on the project location. PG&E uses a value of .238 metric tons of CO<sub>2</sub> per MWh, for example<sup>34</sup>.

The *Production Distribution - Month* sheet describes the monthly use of the CHC equipment, as well as their annual utilization rate. The bottom of the sheet explains the total flows of hot and cold water to various equipment, including the amount of surplus heat released to the environment using cooling towers or radiators.

The *Electricity Use - Season* sheet describes how much of the total campus load originates from each equipment, as well as the season and pricing tier under which it occurs.

The *Electricity Use - Month* sheet lists the monthly electricity use of each equipment, as well as the monthly gas usage of the natural gas water heater.

<sup>33</sup> *Thermal Efficiency of Gas-Fired Generation in California: 2015 Update*, California Energy Commission

<sup>34</sup> <https://www.pge.com/includes/docs/pdfs/about/environment/calculator/assumptions.pdf>

**Figure 19:** CEPOM screenshot; *Electricity Use – Month* sheet

kwh electricity used	Jan	Feb	Mar	Apr	May
CW Distribution	2,820	2,345	2,258	1,916	2,552
HW Distribution	2,401	2,065	1,934	1,946	1,948
GSHE system	0	0	0	0	0
CEP Building	2,232	2,016	2,232	2,160	2,232
Campus Buildings	141,518	125,363	149,458	140,488	148,722
Total	197,169 8%	172,097 7%	194,640 8%	179,738 7%	198,999 8%
mmbtu gas used	Jan	Feb	Mar	Apr	May
H1	21	0	0	-	0
H2	-	-	-	-	-
H3	867	780	715	806	653

### Further Iterations

Once the input data has been collected, it is simple to run the model many times with different parameters. The capacities of the Heat Recovery Chillers, Cold Water chillers, and Hot Water generators can be modified in the *HRC1CAP-HRC3CAP*, *C6CAP-C9CAP*, and *H1CAP-H3CAP* tabs, respectively. The hot and cold water storage capacity and discharge rates can be modified on the *model* sheet. Sensitivities to natural gas price fluctuations or a carbon tax can be analyzed by changing the costs in the *Gas Rates* tab.

To verify that the model solution is feasible, the *Summary Results* sheet has an unmet loads column, which will be nonzero if there are unmet cold and or hot loads during the model run. The flow rates and storage capacities can be lowered until unmet loads appear (**Figure 20**).

**Figure 20:** CEPOM screenshot; Summary Results – unmet loads

GSHE	Unmet loads	Total
	0	279,507
	0	12,465

To make interpreting the necessary equipment capacities simpler, a table was added to the Summary Results sheet which calculates the minimum allowable storage values and equipment capacities, as well as the total heating and cooling cost (Figure 16). To estimate the minimum allowable equipment capacities, the total heat recovery, chiller, and hot water production was identified for each hour of the year, and the maximum value is placed in the table. To estimate the minimum allowable storage, the difference between the maximum and minimum storage value during the year was identified<sup>35</sup>.

### Sanity Check

<sup>35</sup> Note: if initial storage values are set to zero, another method would need to be utilized for estimating required capacity.

To ensure that results from CEPOM are reasonable, another table was constructed in the *Summary Results* tab which calculates the fraction of electricity in the district used for thermal loads, the equipment electricity costs and efficiencies, and the equivalent COP and cooling cost. This table is useful for comparing against the BAU scenario to fine-tune the thermal load assumptions.

**Figure 21:** CEPOM screenshot; Summary Results – Sanity Check Table

Sanity Check		
Total Cooling [CEPOM,ton-hr]	463,093	
Total Cooling [CEPOM,kWh]	1,630,610	
electricity	24.50%	
Implied HRC Efficiency	1.33	kW/ton
HRC Elect. Cost	\$ 0.135	\$/kWh
Chiller El. Cost	\$ 0.135	\$/kWh
Implied Chiller Efficiency	0.438	kW/ton
Implied Heater Efficiency	2	kWh/MMBtu
		kWh cool / kWh
HRC COP	2.65	input
Cooling Cost	\$ 0.029	\$/kWh cooling

## Summary

Using CEPOM as a Decision-making Tool: The key value of CEPOM is that it is optimizing using real, high-resolution historical load and weather data. It is not based upon typical values or hypothetical costs, but actual measured data. This allows it to be instrumental in the development of a new energy system, which many policymakers may not be aware even exists and will be very skeptical of unless given concrete evidence of its performance.

All parameters, including weather data, future network expansions, and varying energy costs, should be considered when sizing the system. One year of weather data may not be representative of the extremes that could occur during the lifespan of the project, and other buildings might be constructed that would like to access the network. Finally, sensitivity to fossil fuel price swings could affect the savings compared to the business-as-usual scenario.

At Stanford University, the CEPOM data informed the selection of equipment, and the model is currently used to provide verified optimal dispatch for the Stanford campus<sup>36</sup>. Therefore, when high-resolution hourly load data is available or if it could be estimated, CEPOM is viable for planning a new thermal microgrid system. However, as discussed earlier, some of the limitations of this tool are relying on Excel Macros for a run (which can be error prone and time consuming) and uncertainty on future availability pending the licensing terms.

<sup>36</sup> SESI Case Study, page 12 [http://www.edf-innovation-lab.com/wp-content/uploads/2018/06/2018\\_SESICaseStudy\\_FINAL.pdf](http://www.edf-innovation-lab.com/wp-content/uploads/2018/06/2018_SESICaseStudy_FINAL.pdf)



### **3.3 Summary of Step-by-step Guides**

The previous subsections were designed to aid the user with learning each of the two thermal microgrid assessment tools, by walking through the setup of a small example network. The first section, RETScreen, provides a pre-feasibility assessment for a combined heating and cooling system with the availability of monthly energy use data. CEPOM is more involved and is useful not only for feasibility studies but for optimizing the operation of an existing system with thermal storage.

As the concept of a thermal microgrid becomes more well-known in the United States, and as focus increases on building electrification and deep decarbonization technologies, we expect more standardized software tools will be developed to help local and regional governments, municipal utilities, and campuses explore its potential. In the next section, we discuss a vision for an optimal thermal microgrid assessment tool.

## 4 Vision for an Optional Thermal Microgrid Assessment Tool

### Introduction

None of the tools reviewed for this study are perfect for a municipality to perform a feasibility study for a thermal microgrid system. However, a few of the tools used in combination with each other may provide a good estimate of a proposed system's feasibility and impact. This section explores a design for an optimal thermal microgrid pre-feasibility assessment tool. It also discusses energy efficiency improvements that should be considered before pursuing the installation of a microgrid system.

### 4.1 Emphasis on Energy Efficiency

Ideally, energy efficiency improvements should be considered for a district before designing a thermal or electric microgrid. In the United States, the energy used by houses and commercial buildings makes up 40% of total energy consumption<sup>37</sup>. Simple upgrades, such as installing LEDs and smart thermostats, can reduce demand charges and energy costs, and other retrofits, such as installing exterior shading systems, can help buildings achieve zero energy building (ZEB) performance goals<sup>38</sup>. This efficiency-first process ensures that capital is allocated optimally, as individual efficiency projects often have short payback periods. It also ensures that a district energy system is not overbuilt to satisfy loads that will be reduced dramatically during the project's lifespan.

Once the majority of the buildings in a district or campus meet up-to-date efficiency benchmarks, more emphasis should be placed on the design and operation of a thermal microgrid system. The result is an optimal design of both the building and system-level infrastructure.

### 4.2 Designing an Optimal Tool

Ideally, assessment of thermal microgrids and other energy system improvements should be based on a tool which is as streamlined as possible for planners and utilities. An optimal tool should not discriminate between projects that consist of a single building versus projects consisting of a whole neighborhood, as both types can benefit from electrification projects. Ideally, the tool should have a simple and intuitive user interface in order to allow decision-makers to use the tool without introducing errors and without omitting important parameters.

The optimal tool should also be able to estimate thermal loads with an hourly or higher resolution, in order to properly size the system to meet peak demands. If not available, smart interpolation or AI-enhanced algorithms should be available to provide the best possible estimates at this resolution. Furthermore, the tool should automatically calculate cost savings, emissions reductions, water use reductions, and other socio-technical or techno-economic impacts of the district energy system versus the business-as-usual case. These metrics should be compared over the full lifespan of the new system, as they provide the justification needed to pursue further in-depth engineering analyses. And finally,

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<sup>37</sup> <https://www.energy.gov/eere/why-energy-efficiency-upgrades>

<sup>38</sup> <http://www.energy.ca.gov/2012publications/CEC-500-2012-049/CEC-500-2012-049.pdf>

the tool should be designed such that uncertainty and variability can be simulated (e.g., Monte Carlo analyses). A step-by-step presentation of such a tool is presented below.

## 4.3 Optimal Tool step-by-step

This section describes the hypothetical four-step process for using the optimal tool. The key challenges associated with each step are also written at the end of each subsection.

### STEP 1: Installing the Optimal Tool

Ideally, the optimal tool would be a standalone piece of software. However, a simplified version could also be released as a web application.

### STEP 2: Data Requirements and Preparation

The following data would most likely be required for proper use of the optimal tool.

- Location
- Costs: Current technology capital costs and retail energy costs
- Current energy provider
- Building Data (type, quantity of each type, size of each type)
- Financial Parameters (lifespan, inflation rate, load growth/loss, etc.)

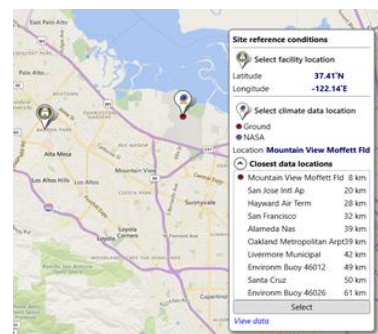
### STEP 3: Setup of System

- Step 3.1 Location, Utility Costs, Emissions:

When starting a new thermal microgrid assessment, the user would use a GUI to identify their project location and select which meteorological data to use for load estimation. The software would then generate parameters such as the climate zone, heating, and cooling-degree-days, etc.

The user would also be prompted to enter their current costs for electricity (\$/kWh) and natural gas (\$/therm), as well as their energy provider (i.e. City of Palo Alto, PG&E, etc.). The software would automatically calculate grid emissions based on the utility selected.

*Potential Challenges:* Development of a database with nationwide meteorological and emissions data would require significant resources and time commitment.



- Step 3.2 Building Data:

Once the location and weather data are input, the user would then input building data. Using a drop-down menu, the user would be able to select the building type, square footage, and site address. If multiple buildings of the same type are being considered, the user could import a file that contains their respective square footages and addresses. The user should also be able to easily remove buildings from the analysis without having to restart the process, as well as analyze a single building. Another variation could involve the user selecting a region manually on a map

*Potential Challenges:* Again, the development of a database of different building types with allowable sizes for each type would require some resources. If one opts for selection on the map feature, it would require development and geocoding of building survey data, zoning data, etc.

- Step 3.3 System Assumptions (Project lifespan, load growth, cost factors):

A thermal microgrid system is a long-term investment, with a lifespan of 20 to 50 years. Therefore, an optimal tool must take future conditions into consideration. The user would be prompted to provide assumptions for future load growth or reduction, cost factors for electricity, gas, and water, and emissions factors that account for a greener future grid.

## STEP 4: Analysis and Results

- Step 4.1 Database:

The model database would first identify the relevant weather data, including climate zone, heating and cooling-degree-days, and building survey data. It would also retrieve the emissions associated with the specified utility.

*Potential Challenges:* Building a database of survey data, including info from tax assessments, zoning, etc.

- Step 4.2 Load Generation Model:

The input parameters defined by the user are fed into a model. This model could use machine learning (ML) to calculate the hourly thermal loads of all the buildings being modeled.

To derive estimates of hourly thermal loads, the ML model will need to use training data provided by various building management systems from different building types, sizes, and climate zones. This allows hourly loads to be back-calculated from the monthly or annual building archetype, input data, and database parameters, providing planners with a robust preliminary estimate of thermal loads.

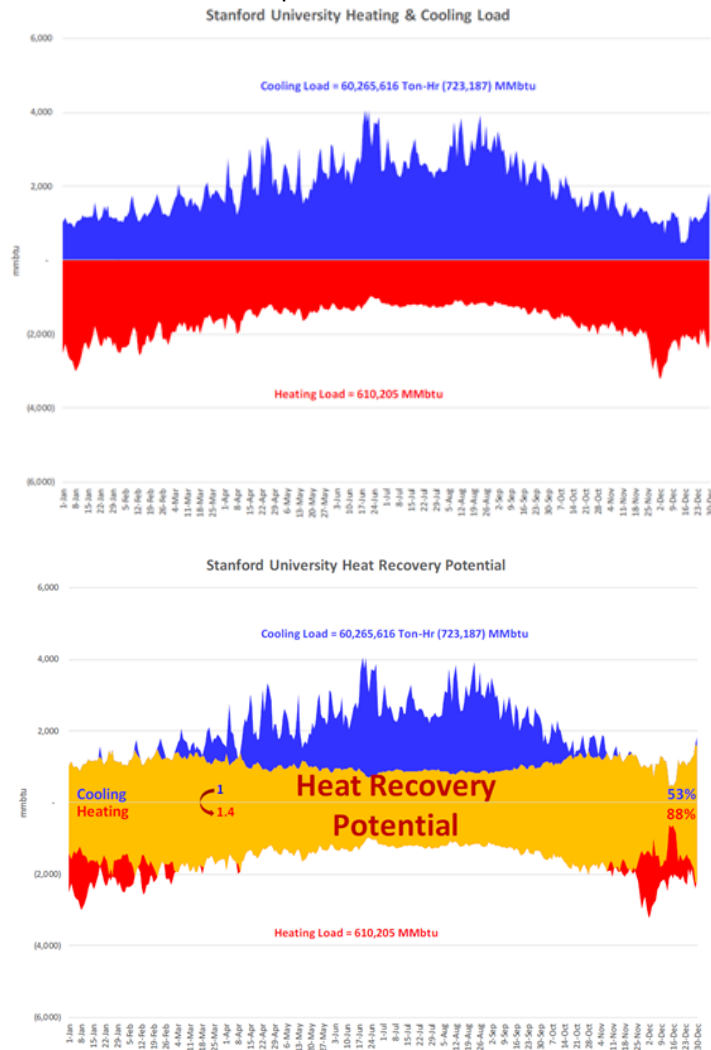
*Potential Challenges:* Data collection for buildings across various regions for constructing ML model

- Step 4.3 Output:

The hourly heating and cooling loads should be presented in both a graphical and tabular form. An example of an 8760 graphical output from Stanford is shown in Figure 22.

It is important for the user to be able to quickly interpret and share the results of the feasibility assessment with others. Therefore, a second graph, which shows the total heat recovery potential, could also be generated for the user. This will help the planner explain the benefits of district energy to policymakers and community members who may be unfamiliar with the technology.

**Figure 22:** A graphical representation of hourly heating and cooling loads and heat recovery potential



- Step 4.4 Comparison Report:

The model will generate a report that considers the following parameters:

- Cost breakdown (capital costs, energy costs, O&M, cost of avoided carbon, etc.)
- Emissions reductions, equivalent vehicles removed from the road
- Financial metrics: payback period, IRR, etc.
- Sensitivity study (a function of cost, load, etc.)

- Step 4.5 Optional Outputs:

The model could also generate the following information if developed further:

- **Pipe network:** A map and table could be generated which documents each segment of pipe within the system. For each section, the start and end coordinates, length, inner diameter, thickness, and insulation type will be specified.
- **Pipe map:** Software could be developed which automatically generates a network topology and overlays it on a map. The map interface would also need to present the pipe parameters that are selected using the mouse.

## 5 Conclusions and Future Work

### 5.1 Conclusion

This report has attempted to demystify the process of performing a pre-feasibility and feasibility study for a thermal microgrid. The most commonly used tools were compiled and reviewed, and two tools - CEPOM and RETScreen- were chosen for an in-depth analysis. A step-by-step guide for each tool was developed for modeling a small-scale district energy system.

### 5.2 Future Work

This white paper is the deliverable for Part 3 of a four-part APPA-funded project, *Leveraging Experience from Stanford and EDF to Develop Information and Tools for Thermal Microgrid Feasibility Assessments*. The following companion deliverable is published separately and relies heavily on the step-by-step guide discussed in this report.

- Part 4: Case studies applying the tools to carry out a techno-economic feasibility assessments of regions within municipal utility service territories. (December 2018)

## Appendix A: Further Reading

The following references provide additional information on existing tools for feasibility assessments of district energy project development.

- [Plan4DE Literature Review](#), IEA (2015). Prepared by Sustainability Solutions Group (SSG) for the Technology Initiative on District Heating and Cooling including Combined Heat and Power (IEA DHC), the report “...takes stock of the literature on district energy, focusing on existing models and the influence of planners. [...] Included in the brief is an exploration of the tools available to planners in considering the impacts of their work on district energy, looking specifically at the state of the modeling field with respect to district energy and at methods (which we term archetypes) to generically characterize the built environment.”



## Appendix B: Equipment Per-Unit Cost Data, Additional Cost Information

Equipment cost data was acquired from Affiliated Engineers<sup>39</sup>. The cost data is presented in Table B.1. **Note:** Equipment per unit costs only include materials, not labor (except for *Entire Chiller Plant* entry).

Table B.1: Per unit cost data for a newly proposed Thermal Microgrid project at Stanford Redwood City campus

Equipment	Unit Cost	Notes
Chiller	\$400/ton	
Heat Recovery Chiller	\$600/ton	
Cooling Tower	\$150/ton	
Pumps	\$100/ton	
Piping	\$250/ton	
Controls	\$100/ton	
Electrical	\$200/ton	
Boilers	\$50/MBH	MBH = Thousands of BTUs per hour
TES	\$2.5/gallon	TES = Thermal Energy Storage
Distribution Piping	\$50/inch diameter and foot length	
Building	\$500/Square Foot	
Building Size	5 Square Feet/ton	For small plants
Entire chiller plant <b>including labor</b>	\$6000/ton	

<sup>39</sup> [www.aeieng.com/](http://www.aeieng.com/)

### Typical Heating Equipment Costs (Canadian \$)

Source: RETScreen

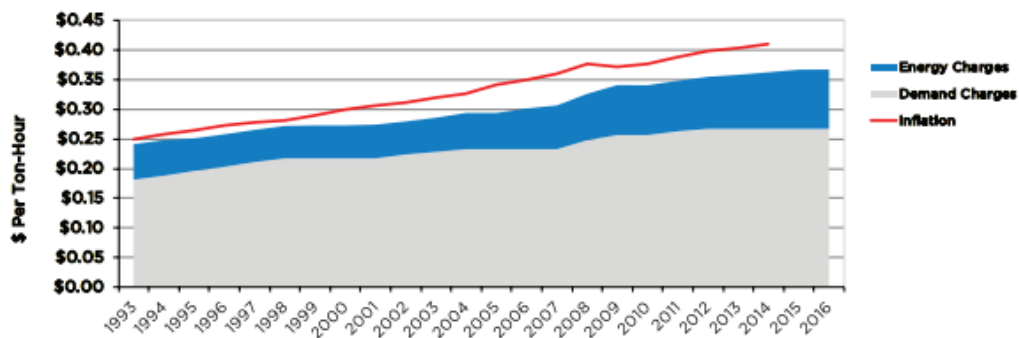
RETScreen heating equipment type	Typical installed cost (\$/kW <sub>heating</sub> )	Included in cost	Not included in cost
Biomass system	100 to 400	• Major equipment • Major installation	• Fuel connections/storage • Flue/Vent
Boiler	25 to 200	• Major equipment • Major installation	• Fuel connections/storage • Flue/Vent
Furnace	30 to 120	• Major equipment • Major installation	• Fuel connections/storage • Flue/Vent • Ductwork, curbs & pads
Heater	30 to 80	• Major equipment • Major installation	• Fuel connections/storage • Flue/Vent
Heat pump - air-source	800 to 1,500	• Major equipment • Major installation	• Fuel connections/storage • Ductwork, curbs & pads
Heat pump - ground-source	600 to 1,500 + 200 to 1,500 for horizontal loop or + 400 to 4,000 for vertical loop	• Major equipment • Major installation	• Fuel connections/storage • Ductwork, curbs & pads

Note: Typical installed cost values in Canadian \$ as of January 1, 2006. Approximate exchange rate at time was 1 CAD = 0.86 USD and 1 CAD = 0.72 EUR.

### Cooling Rate Price Information

Source: District Energy St. Paul<sup>40</sup>

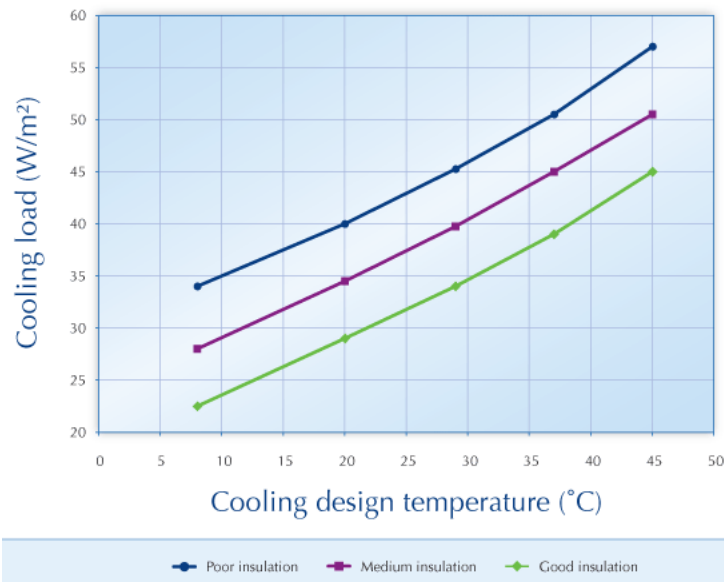
Combined Cooling Rate Summary 1993-2016



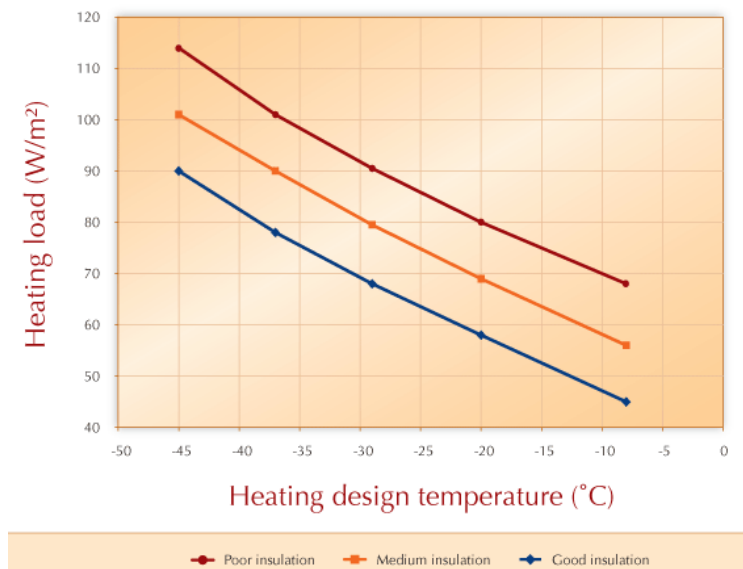
<sup>40</sup> <http://www.districtenergy.com/wp-content/uploads/2015/09/DECRBFY16.pdf>

## Appendix C: Thermal Load Values and Graphics

**Typical Cooling Loads**  
Source: RETScreen Manual



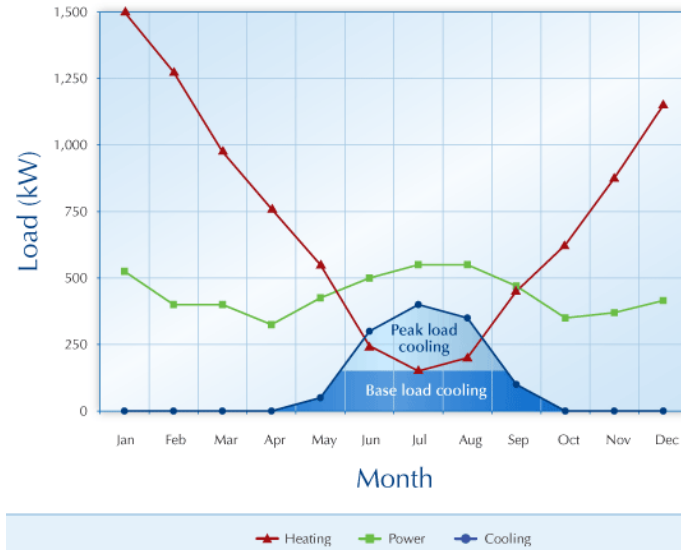
**Typical Heating Loads**  
Source: RETScreen Manual



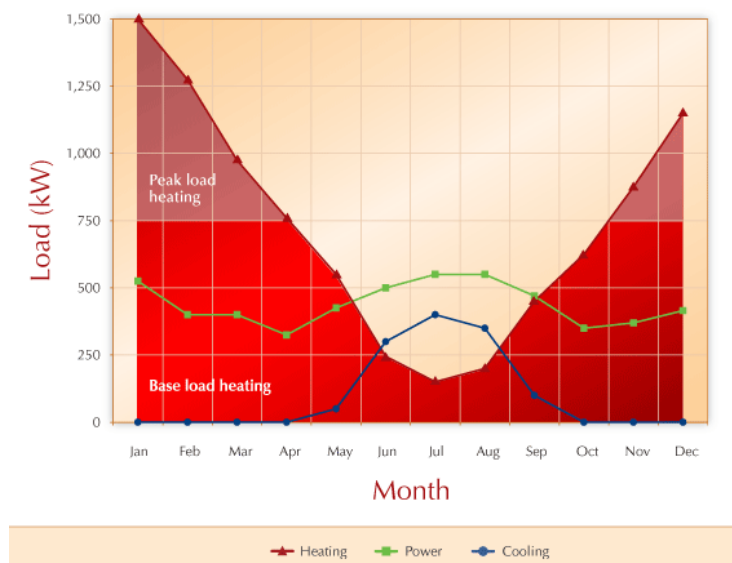
### Domestic Hot Water Heating Demand

According to RETScreen, hospitals typically use 25% of their heating load for water heating. However, an office building only uses 10% of its heating load for hot water. This percentage excludes process heating.

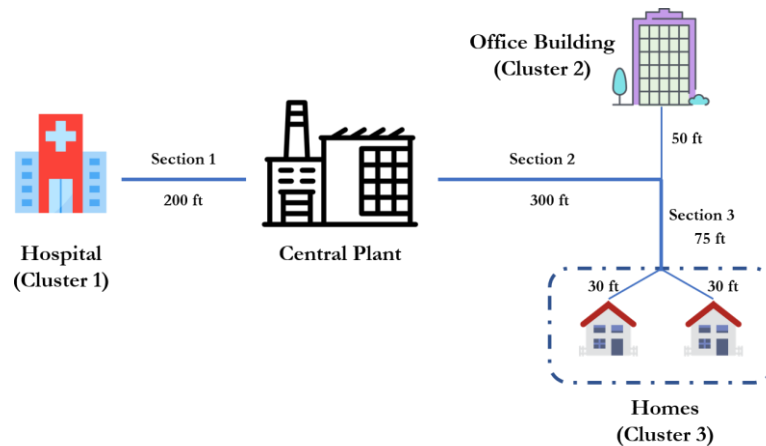
### Base Versus Peak Cooling Demand Source: RETScreen Manual



### Base Versus Peak Heating Demand Source: RETScreen Manual

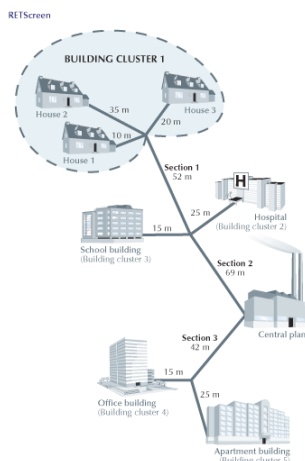


## Appendix D: Example Microgrid Parameters



### RETScreen Additional Sample Parameters

RETScreen provides the following sample pipe section map and associated data sheet. Primary and secondary pipe connections and sizes must be specified.



### Proposed Case District Heating Network

Proposed case district heating network		Estimate/Total	
Heating pipe design criteria			
Design supply temperature	°C	95	
Design return temperature	°C	65	
Differential temperature	°C	30	
Main heating distribution line			
Main pipe network oversizing	%	20%	
Pipe sections			
	Load kW	Length m	Pipe size mm
Section 1	32	52	DN 32
Section 2	169	69	DN 50
Section 3	215	42	DN 65
Section 4			
Section 5			
Section 6			
Section 7			
Section 8			
Section 9			
Section 10			
Section 11			
Section 12			
Section 13			
Total pipe length for main distribution line	m	163	
Secondary heating distribution lines			
Secondary pipe network oversizing	%	0%	
Length of pipe section	m	145	
Pipe size	mm		
Secondary distribution pipes length per building cluster			
		65	25
		15	15
		25	25
		DN 32	DN 40
		DN 32	DN 40
		DN 40	DN 50

## Appendix E: Load Estimation Techniques

Different sources will provide the user with different resolutions for various loads of interest. For example, monthly utility bills will provide the total gas, electricity, and water use for a facility. However, it will not provide details about how resources were consumed within a given month.

### **Use of Smart Meters**

Smart meters can be extremely helpful for better understanding the electricity consumption patterns of a building. Not only can the high-resolution data be used as an input into models such as CEPOM and EnergyPRO to optimize equipment use, but it can also be used to participate in demand response (DR) programs, both of which can save the owner money.

In some cases, smart meters can also track gas consumption with high resolution. This will help the owner understand the usage patterns of gas for space heating, hot water heating, and other uses such as for cooking at a restaurant.

### **Coordination with Building Facility Managers**

Building facility managers will likely understand the typical operation times for different equipment. For example, they might know the exact time when a large office begins to pre-heat in the morning, and the days of the year when this heating is programmed to occur. This allows for a more robust estimation of load profiles for the building, as well as the effect of a district heating system on carbon emissions, as grid emissions per kWh vary with time.

### **Estimation of Loads as a Function of Time and Building Type**

Programs like EnergyPRO make it easy for the user to estimate load profiles for a given building as a function of month, day, or hour. The user inputs annual energy consumption into the model, and then enters how much was consumed in each month. Next, the user can define the *ratio* of energy used each day or hour. From this, EnergyPRO automatically calculates the estimated hourly load profile.