oTherm Facility-level Data Model

Version 1.2

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oTherm Project Task 3:
Facility-level Data Model

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Acknowledgements and Disclaimers

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Introduction

The collection and analysis of data from buildings using renewable thermal technologies (RTTs) has been recognized as a high priority in addressing a number of market barriers. While the oTherm project focuses on ground source heat pump (GSHP) technology as a specific use case, the overall goal is to develop a general framework that can be readily applied to other RTTs.

One major goal of the oTherm framework is to reduce barriers in undertaking performance monitoring of renewable thermal systems. The oTherm framework provides a tool that will enable the synthesis of data that is often sourced and consumed by multiple stakeholders, including building owners, equipment installer/contractor, equipment manufacturers, and program administrators. As such, the documentation for oTherm consists of (1) a set of three best practices documents – each aimed a different stakeholder and addressing complementary concepts, (2) two technical documents that specify the underlying data model, and (3) a set of code documentation for deploying an instance of the oTherm framework. The oTherm framework consists of a backend web application written in Python (Django platform) with two databases (SQL and Time Series) that is 'containerized' using Docker for efficient deployment. The front end and APIs supports efficient data entry and retrieval.

This document, the Facility-Level Data Model (FLDM) Specification, details the portion of the oTherm data model that addresses the characteristics of the facility, the thermal sources, and the renewable thermal equipment installed. This document complements the Device-Level Data Model Specification that details the portion of the oTherm data model that focuses on operating data and the monitoring systems used to collect those data.

The renewable thermal technologies envisioned by oTherm include equipment that produce thermal energy from renewable sources including, heat pumps (both air-source and ground source), biomass furnaces and boilers, and solar hot water system.

Existing Data Models and Dictionaries

oTherm looks to build upon ongoing efforts to develop data standards and data repositories related to building energy usage with renewable thermal systems installed in buildings. There are two Department of Energy supported data standards that are particularly relevant to oTherm. One is the Building Energy Data Exchange Specification (BEDES) which is a dictionary of terms that focus on building energy performance. The second is the National Geotherm Data

System[1] (NGDS) that provides a platform for exchanging geothermal data. Mappings of oTherm facility-level data to both BEDES and NGDS is included in Appendix B.

Previous Heat Pump Studies

The data terms in the oTherm FLDM are guided by several previous studies focusing on the installed performance of heat pumps. The goal is to develop a set of data specifications that are broad enough to address the highly variable configurations common to renewable thermal systems while also capturing the characteristics that are expected to provide the most value in the analysis of operating data. Most of the oTherm fields are optional so the amount of information recorded will depend on both the objectives of the user and the availability of information. The main guiding documents used to develop the FLDM include:

(1) The SEPEMO project (Nordman and others, 2012) measured heat pump performance in 52 sites in several European countries over a one-year period. While they note the importance of detailed site specifications and they typically report the type of heat pump, conditioned floor area, and climate, they did not use a standardized approach to the data elements or the data organization, making it more difficult to assess performance of the portfolio of sites in the context of site characteristics.

(2) In 2016, the Minnesota Department of Commerce published the results of a detailed study of ground source heat pumps in 37 residential buildings (Huelman et al, 2016). In their study, they collected information about the heat pump (capacity), ground loop orientation (horizonal vs. vertical), and ground loop size (number of circuits and length of each circuit).

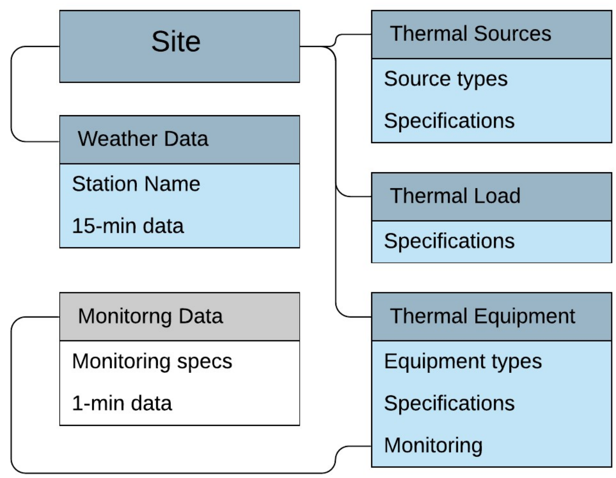
(3) The NYSERDA study of over 50 systems in upstate New York (CDH, 2018) provided one of the more systematic cataloging of site data and has proven to be very useful in interpreting performance data. In addition to conditioned area, heat pump capacity, and type of ground loop, CDH (2018) also included details on pipe sizes, number of pipes in circuit, antifreeze types, freeze protection levels, and design heating and cooling loads. This level of detail provides much greater fidelity in the analysis of operating data.

(4) The Canadian Geoexchange Coalition has maintained a ground source heat pump certification program that collects detailed site information for ground source heat pump installations.

[1] http://geothermaldata.org/content-model/heat-pump-facility

oTherm Data Elements

The organization of the oTherm framework is organized around a 'site' that has one or more pieces of renewable thermal equipment, one or more thermal sources, and a thermal load. The renewable thermal equipment maybe a heat pump, a solar thermal array, and/or a biomass furnace. The monitoring data and the characteristics of the monitoring system for each piece of equipment are detailed in the Device-Level Data Dictionary. To provide context for the monitoring data and the evaluation of performance, the characteristics of the site to which a piece of equipment is associated is described in the Facility-Level Data Model (FLDM).

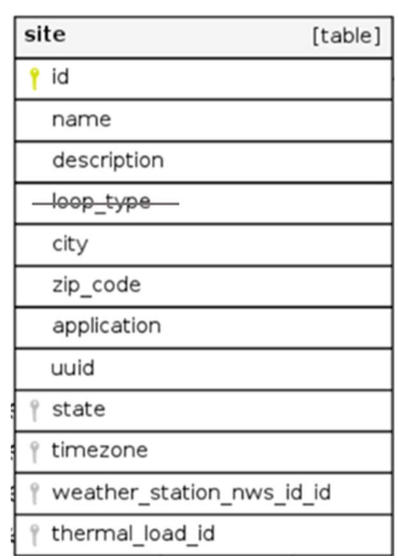


Each thermal source has a set of specifications, depending on the type of the source. For example, a site with a ground source heat pump will have at least one ground loop as a thermal source. The specifications of the thermal source will vary depending on the type of source (for ground sources, a vertical borehole heat exchanger, a standing column well, etc.). The thermal load is described with a building-wide summary of the ACCA Manual J analysis. Future versions of oTherm may extend the thermal load into multiple zones for each site, similar to the handling of multiple thermal sources in the current version.

Site

The site in envisioned as a building with one or more pieces of equipment and one or more thermal sources. Each piece of equipment is associated with a site. Likewise, thermal sources are specified in a separate table that then references the 'site' though the `site_id`.

The `thermal_load_id` points to a separate table, discussed in more detail below, that summarizes the building heating and cooling demands under design outdoor air temperatures.



The explicit attributes of the site include its physical location including the `city`, `state`, `zip code`, and `timezone`. `Latitude` and `longitude` can be entered with different levels of resolution, with the first decimal place representing an area (in New England) of approximately 25 square miles. If not specified, the latitude and longitude will be derived from the zip code provided and will be used for purposes of aggregation (see BPDP Part 2). Each site is also associated with a NOAA/NWS weather station identification (typically four letters, such as 'KPSM' for Portsmouth NH).

Thermal Load

The thermal load represents the total heating and cooling load for a site. In the current version, these are specified as the peak heating and cooling loads and the associated outdoor temperatures for the design. In addition to the loads, the square footage of the conditioned space is included. The data are based a ACCA Manual J calculation, or similar analysis.

thermal_load [table]
uuid
name
description
conditioned_area
heating_design_load
cooling_design_load
heating_design_oat
cooling_design_oat

Future versions may extend that thermal load specifications to include more information, such as loads within individual zones and more detailed information on the hourly or monthly load profiles used in the design.

Thermal Equipment

A site must have at least one piece of equipment for generating useful thermal energy from a renewable energy source. In the current version, the equipment types include air source (ASHP) and ground source heat pumps (GSHP).

equipment [table]
id
uuid
manufacturer
model_id
site
type
...

Manufacturer performance data for different heat pump models can be used as means to estimate thermal production based on energy consumption and/or runtimes (e.g. NH and MA thermal RECs) and are included in the equipment specification tables (discussed below). The equipment performance data in the oTherm database is limited to COP values at full load for a set of source temperatures. Full load is chosen as the standard, as some heat pumps have a single stage compressor. Some oTherm users may choose to maintain complete heat pump performance data tables for their own purposes.

Water source heat pump

Water source (also referred to as ground source) heat pump equipment will typically have AHRI/ISO 13256-1 Performance Ratings for full load capacities (heat and cooling) and corresponding efficiency ratings for heating (coefficient of performance, COP), and for cooling (energy efficiency ratio, EER).

gshp_equipment_spec [table]
equipmentspec_ptr_id
stages_of_operation
hc_at_32F
cc_at_77F
cop_at_20F
cop_at_30F
cop_at_40F
cop_at_50F
eer_at_60F
eer_at_70F
eer_at_80F

To provide the analyst with some baseline metrics, the oTherm database will include AHRI rated values for heating and cooling capacity at full load as well as the associated efficiency ratings. Water source heat pumps can be differentiated based on thermal source as Water Loop (WLHP), Ground Water (GWHP), and Ground Loop (GLHP) Heat Pumps by referencing a different entering water temperature. For example, for Ground Loop Heat Pumps, the AHRI heating and cooling capacities are taken as those with for source side temperatures of 32°F for heating and 77 °F for cooling; for GWHP, the rated temperatures are 50°F for heating and 59°F for cooling; and for WLHP, the rated temperatures are 68°F for heating and 86°F for cooling.

To provide the analyst with additional information so that capacities and efficiencies can be scaled to different source side temperatures, the COP and EER metrics will be entered for a set of discrete source-side temperatures: 20, 30, 40, and 50 °F for heating (COP) and 60, 70, 80, and 90 °F for cooling (EER). While there are some small variations in COP and EER depending on the source-side and load-side flow rates, the intermediate values will be used as representative for a given source-side temperature.

Ground source heat pumps may have different COP and EER values at part load and some users may choose to use more complete tables. Because not all equipment models offer multi-stage operation, the full-load values are selected as being generally applicable.

ashp_equipment_spec [table]
equipmentspec_ptr_id
stages_of_operation
hc_at_5F
hc_at_17F
hc_at_47F
cc_at_82F
cc_at_95F
cop_at_5F
cop_at_17F
cop_at_47F
cop_at_82F
cop_at_95F

Air source heat pump

Heating and cooling capacities and COPs at 47 °F and 95 °F are rated according the AHRI specifications and should be included for all ASHP. Many heat pumps report capacities and COPs at additional outdoor temperatures (typically 5 °F, 17 °F, and 82

°F), and these are included as optional fields in the `ashp_equipment_spec`.

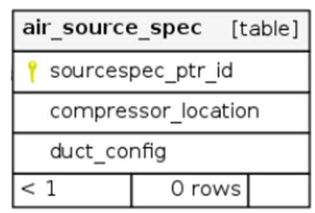
Thermal Source

Thermal source refers to the source of the renewable thermal energy at a given site. A site must have at least one thermal source defined and a site may have more than one source. In the current version, thermal source types [`type_id`] include air source, ground source, and district. Future versions may be readily extended to include other types, such as solar thermal, biomass, or thermal energy storage, each with its own set of attributes.

Thermal source specifications

Thermal sources are organized according to types. The type of thermal source then points to the appropriate table of attributes. Each type of source has a different set of attributes, that are referenced by the `spec_id` through the `source_spec` table. More details on the different sources and their corresponding attributes is provided below.

Air Source



Air source refers to an air-source heat pump as a renewable thermal energy source for a site. The characteristics of the equipment are specified in the equipment specification tables. For an air source heat pump, the location of compressor is often an important factor in the performance of the equipment. The compressor location may consist of roof top or wall mount. The height above the ground surface may also be an important factor to consider[2].

Air source heat pumps can be installed in a variety of duct configurations and the following are also included in the `ashp_equipment_spec` table: single-zoned non-ducted, single-zoned ducted, multi-zoned non-ducted, multi-zoned ducted, multi-zoned mixed.

Ground Source

For systems with at least one thermal source designated as ground source, the characteristics of the ground heat exchanger are specified according to the heat exchanger type. The

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[2] The Cadmus study in Vermont also found that the room in which a ductless system is installed affects performance, consider adding though it is neither a characteristic of the source or the equipment. Perhaps the thermal_load table should designate building level or sub-building.

characteristics of the heat exchanger are those that have the potential to provide the most insight into system performance. Ground heat exchangers are subdivided into five types.

Vertical

vertical_loop_spec [table]
sourcespec_ptr_id
antifreeze_id
formation_conductivity
formation_type_id
freeze_protection
grout_conducitivity
grout_type
ghex_pipe_spec_id

Vertical borehole heat exchangers are assumed to consist of one or more circuits (boreholes) with HDPE pipe circulating the heat conveying fluid. The antifreeze type (e.g. propylene glycol, methanol, etc) is selected from a separate table of antifreeze options and the freeze protection is specified in degrees Fahrenheit. The type of formation can be specified as either the types referenced in GSHP design software (e.g. average rock, dense rock, etc.) or with a brief description of the rock type and characteristics (e.g. 'porous sand and gravel'). The thermal conductivity of both the formation and the grout are specified in imperial units (Btu/ft·hr·°F). A text field description of the grout can be entered as `grout_type`.

Horizontal

horizontal_loop_spec [table]
sourcespec_ptr_id
depth_to_top
depth_to_bottom
ghex_pipe_spec_id
thermal_properties_id
trench_config_id

Closed horizontal ground heat exchangers are typically of two types. The most common is the horizontally trenched ground heat exchanger, and less common is the horizontally bored ground heat exchanger. In this initial version of oTherm, only the horizontally trenched configuration is considered.

For the horizontally trenched heat exchanger, the characteristics follow those outlined in IGSHPA (2009). The `trench_configuration` are selected from the types described in IGSHPA (2006) Table 5.16 (see Appendix A).

ghex_pipe_spec [table]
id
uuid
pipe_diameter
diameter_ratio
n_pipes_in_circuit
total_pipe_length
antifreeze_id
freeze_protection

For both types of closed-loop systems, in which the heat conveying fluid is circulated through HDPE pipe, the characteristics of the ground heat exchanger pipe are specified in a separate table. This specification includes the nominal pipe diameter (in inches) and the diameter ratio (e.g. DR11). The number of circuits is equal to the number of boreholes (or trenches) when flow in each borehole (or trench) is in parallel and is one for a ground loop in series, regardless of the number of boreholes (or trenches). The number of pipes in each circuit is 1 for a single u-tube, 2 for a double u-tube, and 3 for a

Twister heat exchanger. The total pipe length is the total length of pipe in the circuits. For a vertical single u-tube configuration, the total pipe length is expected to be greater than or equal to two times the total borehole length.

Standing Column Well

standing_column_spec [table]
sourcespec_ptr_id
source_well_depth
static_water_depth
supply_return_separation
shroud
bleed
deadband_temp

A standing column well uses a single open water well as the heat exchanger. A groundwater pump circulates fluid from the bottom or top of the well to the heat pump and the water is returned to top or the bottom of the well, opposite the placement of the extraction pump. Performance of a standing column well is affected by the depth of source well, the depth to the static water table, and whether the supply and return are separated by a shroud pipe. The distance between them is the `suppy_return_separation`. In some instances, a bleed circuit is installed so that the supply well can draw water from the aquifer. Both the `shroud` and `bleed` fields are Boolean. If a bleed circuit is present (`bleed = TRUE`), the entering water temperature (°F) that triggers the bleed is the `deadband_temp`.

Open Loop

open_loop_spec [table]
sourcespec_ptr_id
supply_well_depth
return_well_depth
supply_return_separation
static_water_depth
formation_type_id

An open ground heat exchanger consists of two water wells, one acting as a supply and the other as a return. The specifications for an open loop system include the depths of the supply and return wells, and the distance between the wells. The static water depth and formation type are also important characteristics.

Pond

pond_spec [table]
sourcespec_ptr_id
heat_exchanger
antifreeze_id
freeze_protection

Heat exchangers in surface water bodies can take on a wide range of configurations, ranging from a coil of HDPE pipe installed at the bottom of a lake to a plate heat exchanger in a river. For the initial release of oTherm, the Pond Loop specification is limited to a 500-character description along with the type of antifreeze and the freeze protection temperature.

District Loop

The water-source heat pump may have a district loop as the source. The specifications of a district loop most appropriate for oTherm will be determined through the ongoing collaboration with HEET and Eversource on the GeoMicroDistrict pilot projects in Massachusetts.

Weather Station

Current weather observations are collected on 30-minute intervals from approximately 100 National Service Weather stations throughout the northeast US, and this can be expanded for application of oTherm in regions.   The latitude and longitude of each site is used to identify the five closest weather stations and the user can select the station that is most appropriate. Future work will include the calculation of the completeness of the record to aid in the selection process.

weather_station [table]
name
description
nws_id
lat
lon

References

CDH, 2018, Analysis of Water Furnace geothermal heat pump sites in New York State with Symphony Monitoring System, by CDH Energy, submitted to the New York State Energy Research and Development Authority.

Huelman, P., T. Schirber, G. Mosiman, R. Jacobson, T. Smith, and M. Li, 2016, Residential Ground Source Heat Pump Study : A Comprehensive Assessment of Performance , Emissions , and Economics, University of Minnesota Department of Bioproducts and Biosystems Engineering, Cold Climate Housing Unit, OES-01192010-B44645, 146 pp.

IGSHPA, 2011, Ground Source Heat Pump Residential and Light Commercial Design and Installation Guide, Oklahoma State University, 560 pp

Nordman, R. and others, 2012, Seasonal performance factor and monitoring for heat pump systems in the building sector, Final Report, Intelligent Energy Europe, Contract No. IEE/08/776/SI2.529222, 110 pp.

Spitler, J. D., & Gehlin, S., 2020, Measured Performance of a Mixed-Use Commercial-Building Ground Source Heat Pump System in Sweden. *Energies*, *12*(10)

Appendix A: IGSHPA Horizontal Loop Tables

Table 5.16. Common Pipe and Trench Configurations for ¾, 1, and 1-¼-inch Pipe Diameters[1]

Table	Pipe Configuration[2]	# Flow Paths per Trench	D_P (in)	GPM per Flow Path	Single Trench Capacity (Ton)	Minimum Recommended Depths[3] (ft) d_{avg}	d_{bp}	d_{tp}	Common Application
5.17	1-Pipe[4]	½	¾	3.0	½	6	6	6	Two trenches contain a single pipe, out in one trench and back in another, with one flow path.
			1	4.5	¾				
			1-¼	6.0	1				
5.18	2-Pipe Standing	1	¾	3.0	1	6	7	5	One trench contains two pipes, out-back, with one flow path.
			1	4.5	1-½				
			1-¼	6.0	2				
5.19	4-Pipe Standing[5]	1	¾	3.0	1	6	7.5	4.5	One trench contains 4 pipes, out-back-out-back or a 56" pitch slinky, with one flow path.
			1	4.5	1-½				
			1-¼	6.0	2				
5.20	5-Pipe Standing[5]	1	¾	3.0	1	6	7.5	4.5	One trench contains a 36" pitch slinky with one flow path.
			1	4.5	1-½				
			1-¼	6.0	2				
5.21	8-Pipe Standing[5]	1	¾	3.0	1	6	7.5	4.5	One trench contains an 18" pitch slinky with one flow path.
			1	4.5	1-½				
			1-¼	6.0	2				
5.22	2-Pipe Laying	1	¾	3.0	1	6	6	6	One trench contains two pipes, out-back, with one flow path.
			1	4.5	1-½				
			1-¼	6.0	2				
5.23	4-Pipe Laying[5]	1	¾	3.0	1	6	6	6	One trench contains 4 pipes, out-back-out-back or a 56" pitch slinky, with one flow path.
			1	4.5	1-½				
			1-¼	6.0	2				
5.24	5-Pipe Laying[5]	1	¾	3.0	1	6	6	6	One trench contains a 36" pitch slinky with one flow path.
			1	4.5	1-½				
			1-¼	6.0	2				
5.25	8-Pipe Laying[5]	1	¾	3.0	1	6	6	6	One trench contains an 18" pitch slinky with one flow path.
			1	4.5	1-½				
			1-¼	6.0	2				
5.26	4-Pipe Rectangular	1	¾	3.0	1	6	7	5	One trench contains 4 pipes, out-back-out-back, with one flow path.
			1	4.5	1-½				
			1-¼	6.0	2				
		2	¾	3.0	2				One trench contains 4 pipes, 2 out-2 back, with two parallel flow paths.
			1	4.5	3				
			1-¼	6.0	4				
5.27	2-Layer 4-Pipe Laying[5]	1	¾	3.0	1	7.5	9	6	One trench contains two-56" pitch slinkies, hooked in series with one flow path.
			1	4.5	1-½				
			1-¼	6.0	2				
		2	¾	3.0	2				One trench contains two-56" pitch slinkies, two parallel flow paths.
			1	4.5	3				
			1-¼	6.0	4				
5.28	2-Layer 5-Pipe Laying[5]	1	¾	3.0	1	7.5	9	6	One trench contains two-36" pitch slinkies, hooked in series with one flow path.
			1	4.5	1-½				
			1-¼	6.0	2				
		2	¾	3.0	2				One trench contains two-36" pitch slinkies, two parallel flow paths.
			1	4.5	3				
			1-¼	6.0	4				
5.29	2-Layer 8-Pipe Laying[5]	1	¾	3.0	1	7.5	9	6	One trench contains two-18" pitch slinkies, hooked in series with one flow path.
			1	4.5	1-½				
			1-¼	6.0	2				
		2	¾	3.0	2				One trench contains two-18" pitch slinkies, two parallel flow paths.
			1	4.5	3				
			1-¼	6.0	4				

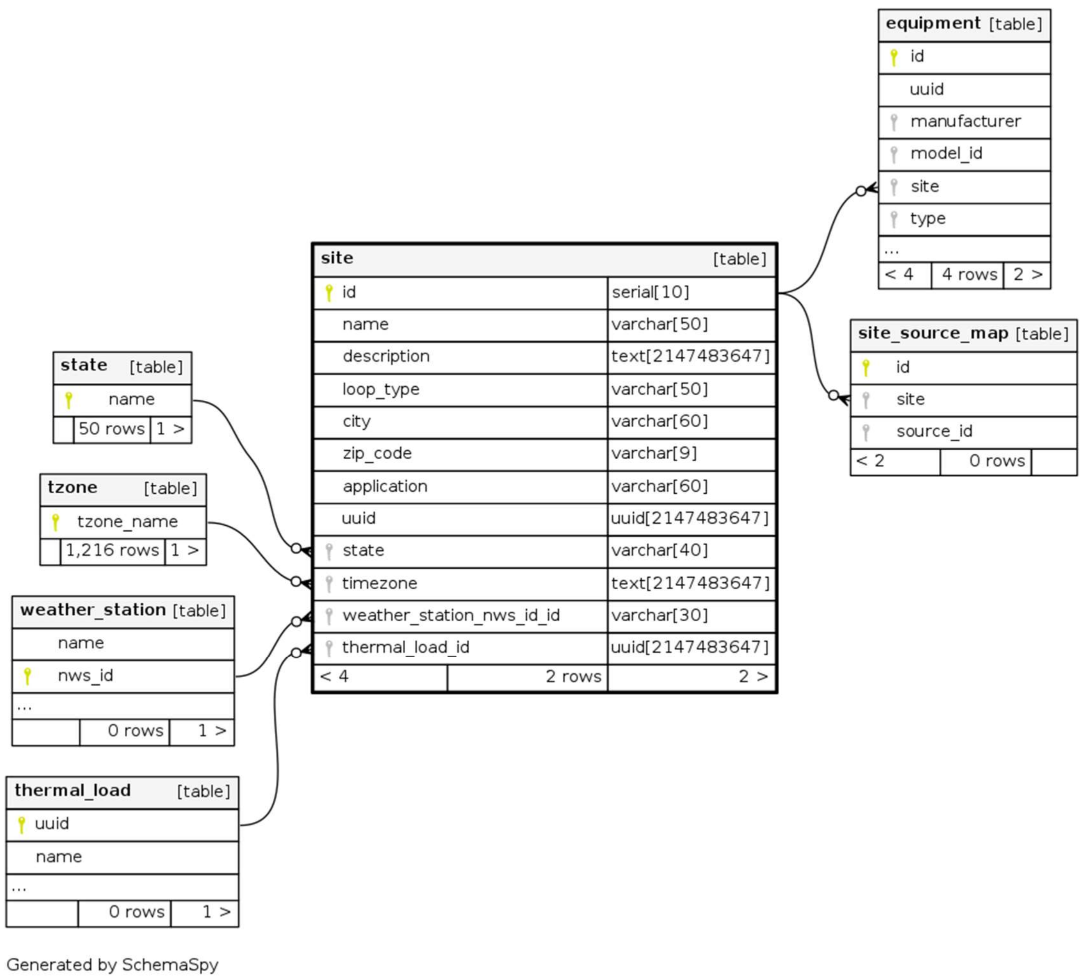
1. Trench configurations assume header trench is located at one end of loopfield.
2. See indicated table for schematic of pipe configuration in the trench.
3. Minimum recommended average burial depths for the configuration (d_{avg}), for the bottom pipe (d_{bp}), and for top pipe (d_{tp}) and to reach thermally stable soil conditions. Burial depth (d_{avg} and associated d_{bp} and d_{tp}) should be adjusted downward (by up to 2 feet) in extremely cold or hot climates.
4. 1-Pipe configuration requires two trenches, one for the supply line away from the header trench and a second for the return line to the header trench, thus only ½ of the flow path exists in a single trench.

Appendix B: Data Table Relations

The main components of the Facility Level Data Model are the site, the thermal source(s), and the thermal equipment. Each have various ancillary tables to provide appropriate detailed specifications. This Appendix provides an overview of the main elements and how they relate to other tables.

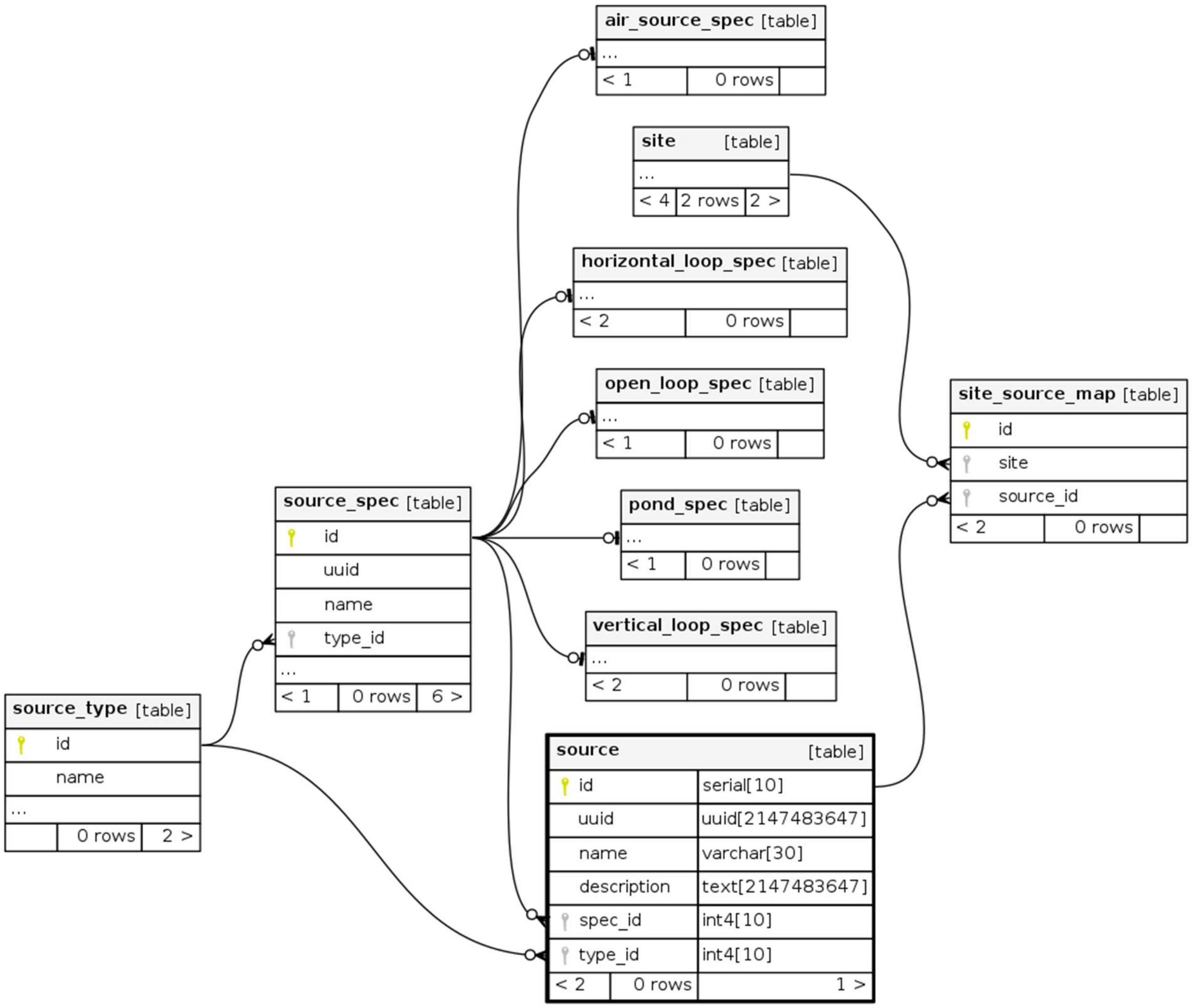
Site

Each site has a set of unique characteristics, such as its location, time zone, and representative weather station. The site is also the reference point for one or more pieces of renewable thermal equipment and one or more renewable thermal sources.



Thermal Source

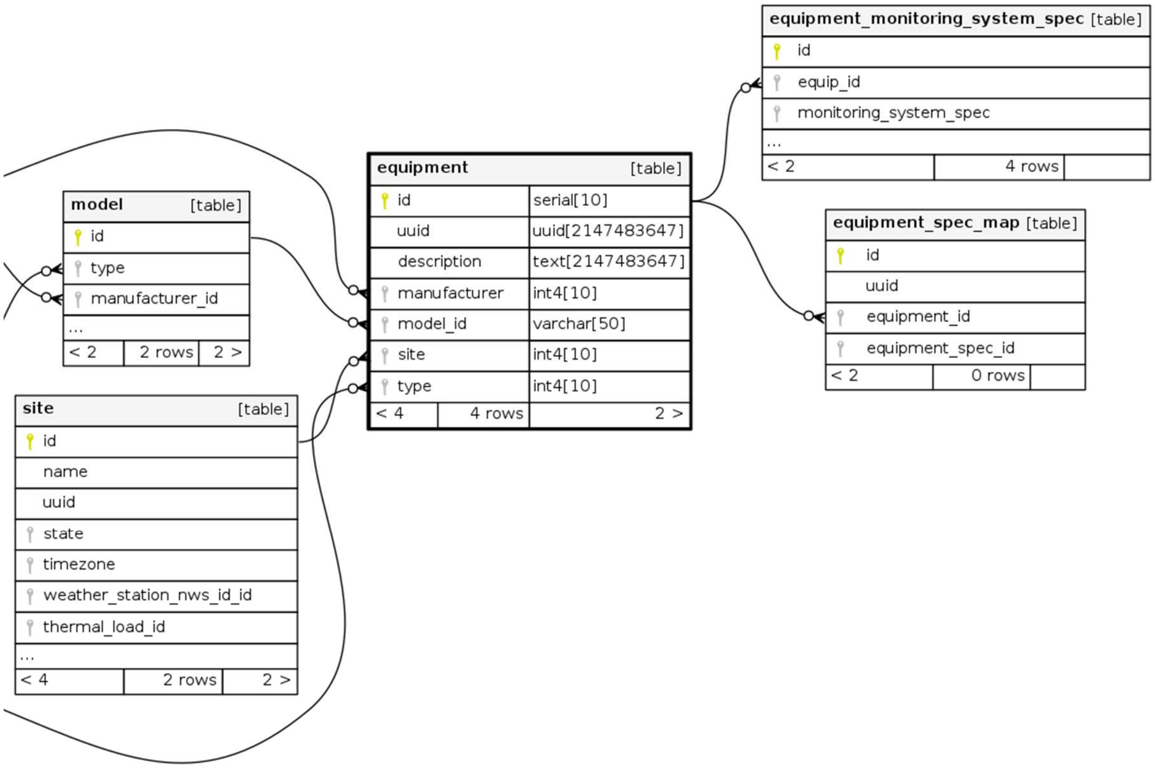
Each thermal source (source) has a unique id that is reference back to the site via the site_source_map table. This intermediate table allows for multiple sources at a given site. Each source has both a source_type reference (e.g. ground source, air sources, etc.) and a specification (spec_id). The `[source][source_spec].id` then maps to the appropriate table, according to the source type.



Note: connect source_spec id to equipment_spec_map id

Thermal Equipment

Each piece of thermal equipment in the oTherm database is tied to a site. Likewise, each monitoring system is tied to a piece of equipment



Note: connect equipment_spec_map to source id or source_spec id

Appendix C: oTherm Mapping to BEDES and NGDS

The data elements of the facility level data model are mapped onto the Building Energy Data Exchange Specification (BEDES) to facilitate the integration of oTherm with other building energy applications. The BEDES dictionary is organized into data terms that each have a data types that include Decimal, Integer, String, TimeStamp, and Constrained Lists. These individual (atomic) terms can also be combined into Composite Terms to provide additional context. For example, the term to describe the area of a building that receives space conditioning (conditioned_area) can be defined by combining two atomic BEDES terms (Conditioned Status = "Conditioned" and Area = [value]) with units of square feet. The creation of composite terms can be subjective and for some terms that were not originally envisioned in BEDES, the mapping can become cumbersome and the benefit of mapping becomes questionable. This is true for many of the oTherm terms that describe specific characteristics of a ground loop heat exchanger.

The National Geothermal Data System (NGDS) has a Heat Pump Facility data model that places more emphasis on the characteristics of the subsurface and the ground heat exchanger. oTherm data terms have also been mapped on the NGDS Heat Pump Facility data model.