HEATMAP©
SOFTWARE FOR DESIGN AND ANALYSIS OF DISTRICT (CENTRAL PLANT) HEATING AND COOLING SYSTEMS

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ABSTRACT

HEATMAP is a software tool developed by the Washington State University Energy Program (formerly Washington State Energy Office) that can provide a comprehensive simulation of proposed and existing district (central plant) heating and cooling (DHC) systems. Use of the program furnishes owners, designers, planners, engineers, utilities, and operators with extensive technical, economical, and air emission information about a DHC application. Program output may be used to evaluate existing system performance or model the effects of various potential alternative system strategies including upgrades, expansions or conversion from steam to hot water distribution. The software can also be a valuable tool for community planners in defining all aspects of developing, evaluating, and justifying a new DHC project or upgrading an existing system. A major feature of the program is its capability to comprehensively analyze various parameters for *both* the supply and return elements of extensive piping distribution systems. Important features of HEATMAP include: the capability to determine reductions in air emissions that can result from DHC or central energy plant implementation; and the evaluation of environmental taxes on economics.

1. INTRODUCTION

HEATMAP is a computer program that provides a fast and reliable method of modeling district heating and cooling (DHC) systems or central energy plants. The program can effectively model both *proposed* DHC projects (e.g., to assist in assessing the technical and economic feasibility) and *existing* systems (e.g., to evaluate system performance and determine the effect of various alternatives for improving operating performance, system expansion or system modification upgrades).

The software is available for Windows (95/NT).

The ***Windows versions*** provide ease of data manipulation, simplified procedures for performing comparative analyses of multiple scenario alternatives, and the acceptance of hourly consumer load data from DOE-2 or an ASCII file. Maximum coincident loading on any pipe described in the heating or cooling distribution model can be determined, as well as, desired scenario analyses to identify effects of consumer or system loads present during any hourly interval of a model year.

New and improved features of the ***Windows 95/NT version*** include: a graphical analysis package covering analytical procedures; metric (SI) capability; AutoCAD Release 13/14 compatibility; international currency units; use of ASHRAE-compatible temperature bin data; insertion of specific pump and valve curve operating data; extensive report generation options; graphical diagnostics; and color plots of distribution system parameters.

HEATMAP functions through the integration of four separate software programs. These programs communicate with each other by means of specially formatted data files and command line arguments. The programs are as follows:

- HM -- central controlling program
- AutoCAD -- computer aided design program (user furnished)
- HEATMAP/AutoCAD Interface program
- LFLOW-2F -- distribution network analysis program

The HM program binds the four components of HEATMAP into a single, coordinated system. Users are provided with a hierarchical system of menus to control program execution, maintain the DHC project database, and govern the exchange of data with AutoCAD *and* LFLOW-2F. HM also controls the printing of reports, and performs the analyses required for estimating heating and cooling loads, selecting and optimizing production plant equipment, evaluating various funding scenarios, and determining life cycle economics.

The HEATMAP program allows the user to establish and maintain a project database that stores a structured, detailed description of the target or existing DHC system. The database and the HEATMAP software are organized to correspond to the six general categories of information and function that are required to complete a DHC project:

- General project description
- Consumer heating and cooling loads
- Production plants
- Distribution system
- Economics
- Reports
- Library (support data)

The user directs the operation of the program using a hierarchical system of menus. A menu bar is present at the top of the screen. The menu provides options, corresponding to the functional categories listed above. When the user selects an option, the program presents a window from which actual program functions are invoked (e.g., data entry or printing reports).

The HEATMAP database is linked to a three dimensional project map that is constructed using user furnished computer aided design (i.e., AutoCAD) software. Note: The HEATMAP© Windows platform is compatible with AutoCAD Releases 13 or 14 for Windows. The location of each DHC consumer and production plant in the database is identified on the map. The map also contains a representation of the distribution network. Each node and pipe depicted on the map is linked to a corresponding record in the project database.

An important feature of the program is its capability to analyze air emissions from existing boiler plants and compare levels of emissions to those that will be present after DHC implementation.

2. SOFTWARE PROGRAM STRUCTURE

2.1 Project Description

The HEATMAP user begins the definition of a new project by providing general information about the target DHC system. Among the data items requested by the program are the following:

- DHC system location
- DHC system name and description
- Type of system (heating or cooling)
- Distribution medium (steam, hot water, chilled water)
- Weather data

On the basis of the values entered by the user, HEATMAP assumes certain default behaviors. For example, if the user specifies a distribution medium of hot water, distribution system pressure and temperature assumptions are altered accordingly.

2.2 Consumer Heating or Cooling Loads and Air Emissions

For each consumer added to the project database, HEATMAP requests annual energy consumption data for space heating, space cooling, and domestic hot water. If the user is unable to provide actual data (e.g., from utility bills), the program estimates the annual load based on the conditioned square footage of the facility and its end use, e.g., offices, school, or residential, etc. Note: If industrial process loads are present in a facility, users should specify the actual load for each process since its energy use will be a function of the specific application. The user may also specify load data calculated by using such programs as DOE-2 or BLAST.

The methodology used for estimating consumer load is patterned directly after COMPACT, a software tool developed by Lawrence Berkeley Laboratory under the sponsorship of the Electric Power Research Institute. The COMPACT computer program calculates an energy utilization index (EUI), expressed in terms of kWh/square foot/year or kWh/square meter/year (in SI units). Separate EUIs are established for space heating, space cooling, and domestic hot water. The EUI calculation is based upon statistical data gathered for over 6,000 buildings across the United States, and an algorithm that adjusts estimated consumption values according to weather conditions at the location of the DHC project.

After annual loads have been determined for each consumer, HEATMAP calculates peak loads. The aggregated annual and peak load totals for all DHC consumers serve as inputs to the procedure that calculates the load duration curve. This procedure requires a variety of other input data, including weather (temperature bin table) and distribution system losses.

HEATMAP also calculates air emissions produced by each consumer, based on the thermal efficiency and the type of fuel used by all of the existing heating and cooling equipment. The program provides estimates for CO_2, SOx, NOx, and particulates; totals are aggregated for the emissions produced by all potential or target DHC consumers.

2.3 Production Plants

The HEATMAP user can specify heating and/or cooling production equipment to operate in either base load or peak mode. Peak equipment is assumed to be capable of operating over a wide load range, and can be brought on line rapidly. Base load equipment is assumed to operate with higher turn down ratios and requires additional time to be brought on line. Combined heat and power generation (or cogeneration) systems produce electricity that is sold at user-specified sales rates and treated as revenue to the project. Production equipment fuel sources include natural gas, electricity, fuel oil, coal, biomass, municipal solid waste, geothermal, heat pumps, and recovered waste heat. Cooling equipment includes steam or electric driven centrifugal chillers, absorption units, and heat pumps. Steam or hot water heating, and chilled water cooling systems can be selected.

The user can provide actual values for equipment performance characteristics such as output capacity and efficiency, or can select default values supplied by HEATMAP.

The cost of energy purchased to operate the production equipment is calculated by HEATMAP on a seasonal basis for winter, mid season, and summer. Seasonal calculations allow the effects of varying energy costs and equipment performance to be considered. The seasonal purchased energy costs and the duration of each season may be specified by the user.

HEATMAP calculates estimates of the air emissions produced by the DHC production equipment, including CO_2, SO_x, NO_x, and particulates. By comparing these values to the aggregated consumer totals, HEATMAP will evaluate emission level reduction benefits for the central plant operation.

2.4 Distribution System

The HEATMAP user designs a complete DHC distribution network on the project map using AutoCAD software. The HEATMAP program "reads" the CAD drawing of the map, and creates a record in the database for each section of pipe and node (consumer or production plant) in the system. HEATMAP correlates the input geographical information with heating or cooling load data and passes an output file to the LFLOW-2F program (Note: information about the LFLOW-2F program is described at the end of this section). LFLOW-2F analyzes the entire distribution system (both supply and return) to determine: pressures; temperatures; flow and thermal energy characteristics for each pipe and node; and pipe sizes if unspecified by input data (e.g., in new systems or expansions). From the results of the LFLOW-2F analysis, HEATMAP constructs an inventory of technical specifications and costs for all system components.

HEATMAP also permits interactive use of the LFLOW-2F program so that the effects of modifying various distribution system parameters (i.e., valves, pumps, pipe sizes, heat transfer coefficients, roughness factors, pressures, temperatures, and flow conditions, etc.) can be examined. Hydraulic and thermal analysis of various distribution system scenarios can help designers and system operators in the identification of many functional benefits including: optimization of heat production, pump heads, and system operating temperatures and pressures; and minimization of heat loss, flow circulation and system energy waste. The program allows for evaluating the effects of meeting peak load and determining flow conditions when new consumers are added to the existing network or if the network is expanded to new geographical areas.

The program includes special features for steam distribution analysis. The effects of leaking steam traps or pipes to the environment or condensate return can be calculated. Steam systems without any condensate return provisions can be modeled. It is also possible to use the model for evaluating steam to hot water conversion scenarios.

LFLOW-2F is the core program of LICHEAT, a software system developed by LICconsult of Birkerød, Denmark. The program is used to model and analyze the physical characteristics and behavior of distribution networks in over 200 operating DHC systems worldwide. LFLOW-2F was selected for use with HEATMAP based on its widespread acceptance and field testing.

2.5 Units

HEATMAP (Windows 95/NT version) has been designed to support both Inch pound-second (IPS) and Metric (SI) units for technical data input and map scaling. All major international currencies may be specified for economic evaluations.

2.6 Economics

The economics features of the program permit evaluation of projects by conventional economic methods.

Conventional Analysis

On the basis of the project conditions specified by the user, HEATMAP will calculate the necessary break-even unit sales price for each consumer by mode of operation, i.e., heating production (hot water or steam) and cooling production (chilled water).

Prices are calculated for ***each year*** of the project ***and on a levelized basis*** throughout the project life. Both public and private ownership's can be considered.

The sales prices are calculated based on the "minimum acceptable revenue requirement" financial model. The general calculation approach involves determining the required revenue stream associated with each production plant's operating expenses (e.g., purchased energy, operating labor, equipment maintenance and repair, debt, taxes, and others). Required return on investment is treated as an expense item. The gross revenue that must be present for the plant to operate profitably is determined from the sum of all revenue streams generated by the plant operation. By calculating the required gross revenue for each year of the project life, and knowing the annual heating and cooling production send out, HEATMAP will determine the average sales price.

Special features of the HEATMAP economic analysis module include: debt financing from bonds or bank loans; equity financing; ability to annually escalate cost factors including capital equipment, fuels, operating labor, and maintenance costs; separate construction and long term debt financing; income tax calculations including various tax depreciation methods; tax credits; income stream for thermal sales; electrical sales (cogeneration); tipping fees; consequences or impacts of environmental taxes applied to different fuels or production methods; and a sensitivity analysis of sales price versus key production plant operating expenses.

2.7 Library

The HEATMAP library contains a wide variety of information from which default values and assumptions are obtained for use throughout the program. For example, the program requires information about fuel types for the analysis of DHC production units *and* existing consumer heating or cooling equipment. To estimate air emissions, HEATMAP uses library information on weather data as well as all other pertinent factors needed to perform the necessary calculations.

In most cases, the data in the support library is stored and manipulated in the form of tables. A table consists of rows (records) and columns (fields). The table of fuel data, for example, contains a row for each fuel type recognized by HEATMAP. Each row consists of seven columns: fuel name, unit name, conversion factor, and levels for each of the four emission categories. Data tables are maintained for six categories of information:

- Weather Data
- Fuel Data
- Statistical EUI Data
- Production Unit Data
- Consumer Heating and Cooling Equipment Data
- Pipe Data

The user **may modify existing data** *or* **create new files** that are *"tailored"* to the project analysis. The following summarizes the information stored under each category in the library:

2.7.1 Weather Data

Weather data is used by the algorithms that estimate heating and cooling loads. During description of the DHC project, the user specifies an appropriate weather data record by selecting the name of the city that corresponds to the location of the DHC. Each record contains the following elements:

- City name
- Latitude
- Annual heating degree days
- Annual cooling degree days
- Solar factor
- Outdoor heating and cooling design temperatures
- Hourly temperature bin table (ASHRAE compatible intervals)

2.7.2 Fuel Data

The table of fuel data contains a record for each fuel type that may be used by consumer heating and cooling systems, or DHC production plants. Each record contains the following fields:

- Name of fuel
- Name of fuel units
- Conversion factors
- Emissions characteristics
- Rate schedule

2.7.3 Statistical EUI Data

In addition to weather data, the algorithms used by HEATMAP to estimate heating and cooling loads require a variety of inputs related to energy use, including statistical averages for EUIs and values for certain operating and design characteristics that affect internal gains and heat losses. These data items are stored in separate tables in the database. Each table contains nine rows, one for each use type defined by the program. Each row of the table contains the following fields:

- Space heating EUI
- Space cooling EUI
- Domestic water heating EUI
- Area per worker
- Customers per worker
- Ceiling U-value
- Wall U-value
- Window to wall ratio

2.7.4 Production Unit Data

A DHC production plant is defined by selecting production units from a list of equipment descriptions. The descriptions correspond to records in the library that contain information about the operating characteristics of the selected equipment. Production unit equipment includes: boilers or cogeneration units fired with oil, gas, coal, or biomass; MSW incinerators; heat pumps; geothermal wells; and steam or electric centrifugal and absorption chillers. A production unit record contains the following fields:

- Unit description
- Fuel
- Average seasonal efficiency
- Generating efficiency (for cogeneration)
- Electric input ratio
- Air emissions reduction ratios
- Estimated air emissions

Subsidiary to each production unit record is a related table of data that contains one record for each size (hourly output capacity) in which the unit is available. The information stored in these records is used primarily to determine the costs to purchase, install, maintain, and operate the selected production unit. Each record contains the following fields:

- Hourly output capacity
- Electric generating capacity (for cogeneration)
- Cost to purchase

- Land area required
- Mechanical room area required
- Personnel required for operation
- Maintenance costs
- Cost of technology to achieve desired emissions reduction ratios

2.7.5 Consumer Heating and Cooling Equipment Data

When a consumer is added to the database, the user identifies the type of equipment used for space heating, space cooling, and water heating. This information is used to estimate the quantity of emissions produced by the consumer, and to assess the difficulty of retrofitting for connection to the DHC. The user selects equipment from a list of descriptions that correspond to consumer equipment recorded in the library. Each record contains the following fields:

- Equipment description
- Retrofit difficulty
- Fuel
- Particulates emitted per unit of energy
- Carbon dioxide emitted per unit of energy
- Nitrogen dioxide emitted per unit of energy
- Sulfur dioxide emitted per unit of energy

2.7.6 Pipe Data

To design, size, and analyze a DHC distribution network, the LFLOW-2F program requires HEATMAP to supply a table from which pipes of appropriate materials and diameters can be selected. The library contains several such tables, representing a variety of pipe materials suitable for transmission of hot water, chilled water, and steam. The user selects the desired type of pipe from a list of names corresponding to the tables stored in the library. The tables contain a row for each diameter in which the selected pipe is available. Each row contains the following fields:

- Pipe Identifier
- Diameter
- Roughness
- Loss coefficient
- Cost
- Trenching refilling and resurfacing costs are user defined

3. PLANNED UPGRADES

Planned upgrades to the existing program include the development of a generic graphical interface that will accept DXF input files generated by *any* CAD or GIS program, expansion of the LFLOW program capability to 15,000 nodes and thermal storage, dynamic 8,760 hour energy analysis capability for precisely simulating production plants, cogeneration and storage, tailored use of heat distribution system for distributed absorption cooling applications, and additional features to permit even more comprehensive system-modeling capabilities.

4. HEATMAP© SPONSORS

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