COOLING, HEATING, AND POWER APPLICATION SCREENING TOOL

Steve Fischer, R&D Staff, Oak Ridge National Laboratory, Oak Ridge, Tennessee, USA
R.C. DeVault, Cooling, Heating and Power Group, Oak Ridge National Laboratory, Oak Ridge, Tennessee, USA

ABSTRACT

Over half of the energy of the fuel burned to produce electric power at conventional power plants is rejected to the environment while only 30% to 35% is delivered to the end user as electricity. Large district energy systems recover a significant portion of the waste heat and distribute it to nearby homes and businesses for space heating, hot water, or sometimes space cooling. There are instances where the energy and cost savings of power generation and heat recovery can be realized on a smaller scale through cooling, heating, and power – integrated energy systems (CHP-IES) for individual buildings or small campus settings. The U.S. Department of Energy undertook this project to develop an accurate, easy-to-use computational tool for estimating the economic viability of CHP-IES in the United States.

Key Words: ***cooling, heating, and power – integrated energy systems, CHP, IES, on site generation***

1 INTRODUCTION

Over half of the energy of the fuel burned to produce electric power at conventional power plants is rejected to the environment while only 30% to 35% is delivered to the end user as electricity. The United States consumed 24.5 EJ of fossil fuel based energies in 2001 to produce electricity, rejecting 14.8 EJ of waste heat to the atmosphere, rivers, and lakes (MER 2001). Recognizing this wasteful use of scarce fuels, the U.S. Department of Energy (DOE) had already begun the process of educating the public, reducing barriers, and developing technologies to recover and use heat from the power generation process. In 1998, as part of their efforts to increase energy efficiency and reduce emissions of carbon dioxide, DOE set the goal of doubling the installed capacity of cooling, heating, and power – integrated energy systems (CHP-IES) systems in the United States by 2010. The United States Combined Heat & Power Association organized a series of events across the U.S. that culminated in the National CHP Roadmap Workshop in October 2000. The participants in this workshop identified the development of computerized screening tools as one of the high priority projects needed to attain the CHP goal (United States Combine Heat & Power Association 2000).

Working through Oak Ridge National Laboratory (ORNL), DOE developed a statement of work (SOW) for the development of a computer program and associated databases for screening the use of CHP in commercial buildings in the U.S. The SOW stated that the proposed models employ hourly building space heating, hot water, space cooling, and electric demand for typical meteorological year (TMY) weather conditions for any of 239 cities in the U.S. and 14 different building types. It also stated that the model should include databases of cost and operating parameters for on site generators including reciprocating engines, gas turbines, microturbines, and fuel cells. There also had to be a database of parameters of electrical and thermally activated chillers, rooftop air conditioners and heat pumps, gas and electric boilers, and desiccant dehumidification systems.

DOE issued a request for proposals (RFP), bids were received and evaluated, and a contract was awarded to GARD Analytics of Park Ridge, Illinois to develop the BCHP Screening Tool to evaluate the economic viability of CHP systems in commercial buildings in the U.S. The program employs the well known building loads program, DOE2.1e, in a manner that is completely transparent to the user. The BCHP Screening Tool organizes the user's selections from a table of building and equipment parameters and operating schedules into a form that can be used by DOE2, invokes DOE2 to perform the hourly simulations, and then organizes the results into a table of output results. GARD delivered the BCHP Screening Tool Version 1.2 to ORNL and DOE in October 2003 (Glazer et al 2003); ORNL has been responsible for distributing the program to the public.

Early users of the BCHP Screening Tool tended to treat the program as a "black box" focusing most of their attention on the bottom line, the estimated simple payback period or the life cycle cost of a proposed CHP-IES system relative to the conventional building relying exclusively on utility power. The tabular display of results hindered users from getting a clear understanding of how to alter their data selections in order to get a more efficient or more economically viable combination of equipment and sizes. Between June and December of 2004 ORNL implemented changes to the BCHP Screening Tool that provide a visual display of the energy flows into and out of each major component of the CHP-IES system as well as displays of the hourly equipment loads and efficiencies.

2 WEATHER AND BUILDINGS

As mentioned previously, the hourly building loads are calculated using the TMY hourly data for 239 cities in the United States. These data are compiled from 30 years of observations that include dry bulb and dew point temperatures, relative humidity, atmospheric pressure, wind direction and speed, precipitation, and solar radiation. Additional information on these data can be obtained from Marion and Urban (1995).

Through past efforts, DOE has identified 14 types of commercial buildings that are "typical" of construction and usage in the U.S. Usage patterns, thermostat settings, lighting intensities, etc. for these building types were built into the BCHP Screening Tool so that they can be selected by a keyword describing the building type. These include:

- Hospital
- Nursing home
- School
- Supermarket
- High rise office building
- Low rise office building
- Large Hotel
- Small hotel
- Full service restaurant
- Quick service restaurant
- Retail store
- Refrigerated warehouse
- Theater
- Ice skating rink

Each of these building types is assumed to be comprised of space allocated to 20 types of rooms:

- Auditorium
- Classroom
- Clinic
- Conference room
- Dining room
- Enclosed office
- Food sales
- Guest rooms
- Gym/pool
- Hallway or corridor
- Ice rink
- Kitchen
- Open office
- Patient rooms
- Refrigerated loading dock
- Refrigerated storage
- Restrooms
- Retail sales area
- Storage rooms
- Surgical operating rooms

The building thermal and electrical loads are calculated by dividing the building into six zones (each zone has calculations for their perimeter and core heating and cooling loads). Room types are assigned for each of the zones along with typical values for the fraction of the building occupied by that room type and the fraction of the outside wall area containing windows. Each building type is also assigned a default, typical, operating schedule. Default parameters are also assigned for building wall and roof construction materials, insulation levels, types of window panes, etc. and building dimensions that the user can change to model a building of the desired size and type of construction.

3 UTILITY RATES

The SOW for the GARD contract called upon them to provide a database for the commercial business rates of 160 electric utilities and 160 gas utilities in the U.S. Over 3100 individual rate tariffs were identified and documented in this effort and provided as input data files for use by the BCHP Screening Tool. Independently, GARD developed a computer program called the RateScriptEditor that they used to generate the data files from the utility rate sheets. This program is distributed with the BCHP Screening Tool so users can update the utility rates as they change over time or create files for utilities not included in the original survey.

4 EQUIPMENT DATABASES

The equipment plant calculations employ manufacturers' data for power or fuel input, power or heat output, and coefficients for curve fits for degradation of performance from rating conditions due to part load operation or elevated temperatures. These parameters are all described in the DOE2 documentation (DOE-2 1980). GARD assembled this information into two Microsoft Access™ databases; one library of manufacturers' data that cannot be edited and changed and another "user's" database. Users can copy records from the library of manufacturers' data into the user's database where they can then edit entries to alter the cost or performance parameters to simulate equipment omitted from the manufacturers' database or to perform "what if" type of calculations. Each of the two databases contains "groupings" of equipment for generators, chillers and air conditioners, boilers, cooling towers, cool thermal storage systems, hot thermal storage systems, water heaters, and desiccant dehumidifiers.

4.1 Generators

The manufacturers' database for generators includes 88 entries for commercially available generators ranging in size from 23 to 25,100 kW and includes reciprocating engine-driven generators, gas turbines, microturbines, and fuel cells. Data parameters include:

- Rated electrical capacity
- Rated electrical efficiency
- Fraction of jacket cooling water and lube oil heat that can be recovered
- Fraction of exhaust heat that can be recovered
- Maximum and minimum operating ratios
- Coefficients to degrade performance for part-load operation and for elevated ambient temperatures, and to decrease the jacket and exhaust heat recovery for part-load operation
- Equipment and estimated installation and non-fuel operating and maintenance costs, and
- Emission rates for CO_2, CO, NOx, and SOx.

Users select equipment entries from the database using the "point and click" techniques that have become standard in Microsoft Windows™ applications.

4.2 Heat Recovery

The BCHP Screening Tool, and the underlying DOE2, match kilojoules of heat recovered with building or equipment loads and do not perform an explicit accounting for heat recovery and application temperatures. Heat sources are broken down into three temperature ranges (e.g. engine exhaust, jacket and lube oil coolers, and fuel cell cooling water); energy recovered in each temperature range is "mapped" to an appropriate thermal load (e.g. single- and double-effect absorption chillers, process heating, space heating, service hot water, desiccant regeneration). Medium grade heat from engine jacket cooling water, for instance, can be applied to a concurrent need for a single-effect absorption chiller or service hot water but not for a double-effect chiller. High grade heat from engine exhaust can be applied to meet any concurrent thermal load. Low grade heat from a phosphoric acid fuel cell can only be applied toward space heating or service hot water.

4.3 Chillers, Boilers, and HVAC Equipment

The manufacturers' database for HVAC equipment includes entries for 166 commercially available models of air conditioning equipment. These include:

- Electric chillers including 37 centrifugal, 20 reciprocating, and 28 screw chillers
- 17 models of direct-fired double-effect absorption chillers
- Indirect (steam) fired absorption chillers including 13 single-effect and 12 double-effect chillers
- 4 engine-driven chillers
- 21 rooftop air conditioners with either electric strip heaters or gas packs, and
- 14 electric heat pumps

Buildings with chilled water systems are always assumed to use a gas or electric boiler for both space heating and service hot water. Buildings with rooftop air conditioners or heat pumps are assumed to have a separate gas or electric service hot water system. There are 44 models of boilers included in the database and 80 models of water heaters. The data parameters for the HVAC equipment are similar to those listed earlier for the electric generators.

5 COMPUTER MODEL

The BCHP Screening Tool is designed to be used in an interactive mode on a desktop or laptop personal computer. Conventional Windows™ techniques are used for moving around the screen using the computer mouse pointer and entering data. The user can assemble up to 26 separate "cases" to be simulated with the first one serving as a baseline and all of the others compared to it for simple-payback periods, life-cycle costs, and emission reductions. Curves are built into the program for adjusting normalized costs of electricity and natural gas to projected costs by the EIA over a 30 year period. Annual and monthly energy use, electric demands, and utility costs are calculated. DOE2 algorithms can be used for sizing HVAC equipment and generators.

5.1 Input / Output Screens

Figure 1 shows an example of the primary data tables on the program screen. Across the top of the figure there are menu items and buttons for running a simulation with the current data settings, saving data files, etc. The input data table is below that. This example contains two columns of data entries; case A for the baseline calculations and case B for the first CHP-IES alternative. Menu items can be used to add additional columns of data (or to delete columns). Each row of this table contains default values for each of the parameters needed for the building energy simulations. Users can change values in this table by clicking the mouse (or double-clicking in some instances) and typing in new values or selecting from a drop-down list.

The output table is below the input table on this screen. Each row of the table is labeled with what variable is displayed, its units of measure (the BCHP Screening Tool uses inch-pound units exclusively, so the figures are labeled in inch-pound units), and the value computed for each case simulated. The scroll bars at the right of the screen and across the bottom can be used to view rows of information above or below the current selection or columns that are outside the range of the screen. In typical Windows fashion, the user can select all or portions of the input or output to copy into other software applications.

The second “tab” on the user interface can be used to look at graphs of the calculated building and equipment loads. Figure 2 shows load duration curves for purchased electric power for the baseline and CHP-IES alternatives shown in the input grid in Fig. 1. Load duration curves can also be shown for the thermal loads (i.e. space heat and hot water and inputs to indirect-fired absorption chillers) and chilled water loads using the radio buttons at the bottom of this page. Bar charts can also be shown showing the distribution of electric power and on site generation or boiler steam and recovered heat for a single 24 hour period (selected in the input grid).

The third tab on the user interface can be used to view a schematic diagram of each system and also to use the diagram as an alternative means of data selection. Figure 3 shows an example of the output parameters displayed on a schematic diagram labeling the energy into and out of each major component of the CHP-IES. The “radio buttons” in the upper left of the diagram are used to determine which case is displayed. The economic comparison with the baseline system is displayed at the upper left and the building electric, heating, and cooling loads along the right edge. Within the diagram there are rectangles depicting the major system components (e.g. generator, lead and lag chillers). Each line leading into or out of one of the rectangles is labeled with the corresponding energy into or out of that component. The generator, for instance, is labeled with natural gas going in from the bottom, electricity coming out at the top, and waste heat coming out on the right.

The schematic contains “hot spots” that can be used either to invoke a data selection form or to view hourly results. Moving the mouse pointer over any of these hot spots causes the labels to turn red. Clicking on the hot spot makes something happen. Clicking on the rectangle for the generator, for instance, triggers the data entry form shown in Fig. 4. This form displays the database parameters for the currently selected generator, curves showing the generator efficiency, heat recovery, and capacity across ranges of operating conditions, and drop down lists for selecting a different generator or changing the generator operating schedule.

5.2 Hourly Equipment Performance

Clicking on the label for the fuel into the boiler, or the heat out of the boiler, invokes the form shown in Fig. 5. This form has “scrolling” bar charts and tables that show the hourly operation of the boiler and heat recovery heat exchanger. Clicking on the triangle at either end of the horizontal bar causes the bars displayed to shift one hour to the left or right. Clicking within the scrolling area moves the bars 24 hours at a time. The scroll indicator can be dragged with the mouse to make large steps in time to see summertime operation. This data form contains information other types of information on additional tabs. Figure 6 shows statistics for heat recovery and a distribution of the number of annual hours heat was recovered across the entire range of heat recovery rates. Figure 7 shows scrolling tabular data for thermal plant operation. Similar charts are shown in Figs. 8 and 9 for chiller and generator operation.

6 CONCLUSION

DOE has set an ambitious goal of doubling the capacity of installed CHP-IES in the U.S. by 2010. Much of the potential for new installations is in the area of commercial buildings. The BCHP Screening Tool is a valuable tool for assessing whether or not a particular building, in a particular location with site specific utility rates can be economically viable. Users can assign data for a coarse representation of the building of interest, select from the utility rates provided or tailor make data sets for their specific needs, and run simulations that provide them with detailed information on energy use and operating costs. The load duration curves, equipment statistics, and hourly outputs can be used to make informed choices in refining data selections for types, capacities, and operating schedules of equipment in order to improve system economics. Users can then make informed recommendations as to whether building owners or operators should invest in a more detailed analysis of a CHP-IES for their building.

REFERENCES

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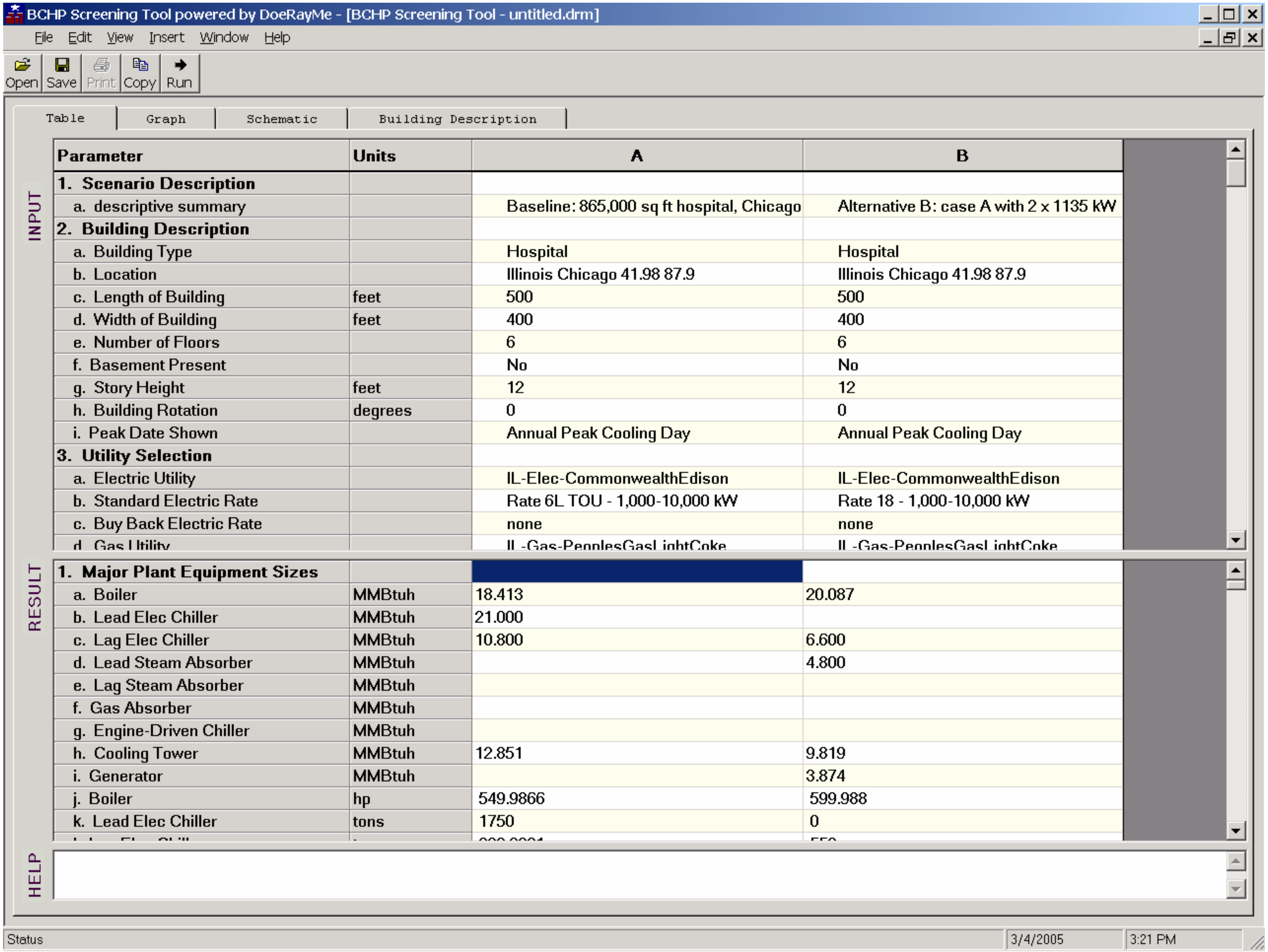


Fig. 1. Input and output data grids in the BCHP Screening Tool.

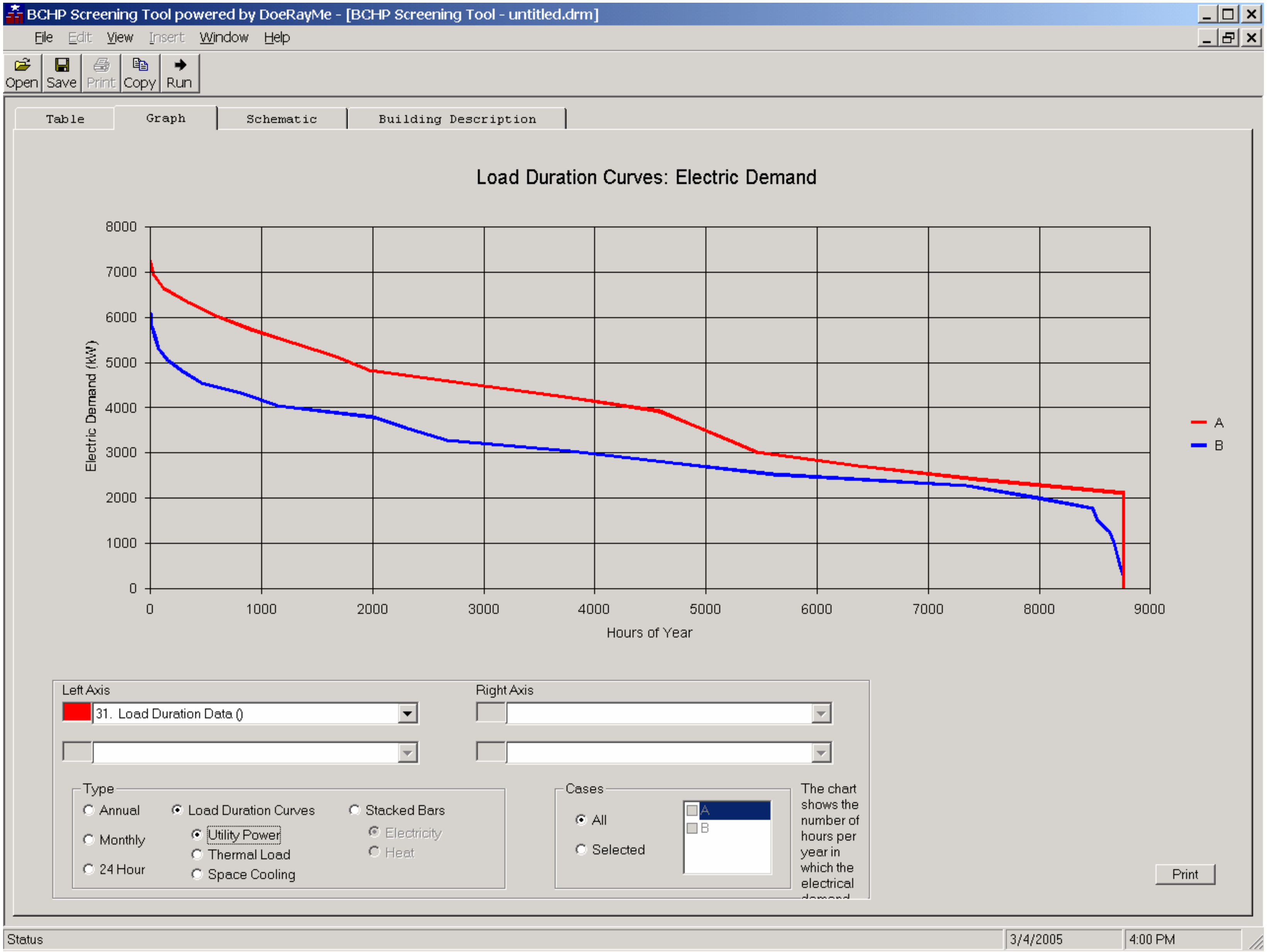


Fig. 2. Electric load duration curves for cases A and B.

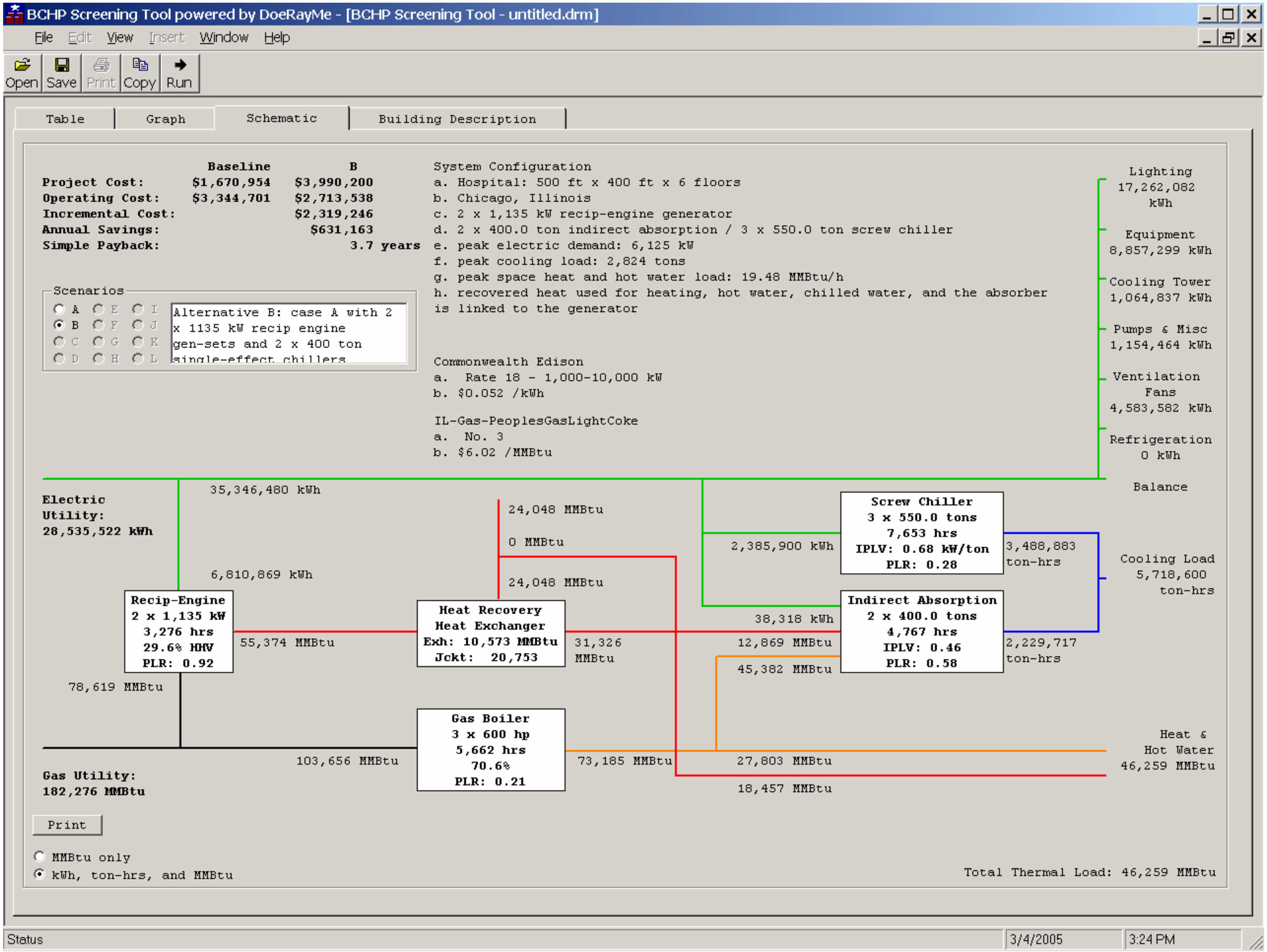


Fig. 3. Schematic diagram showing energy flows between major components and loads.

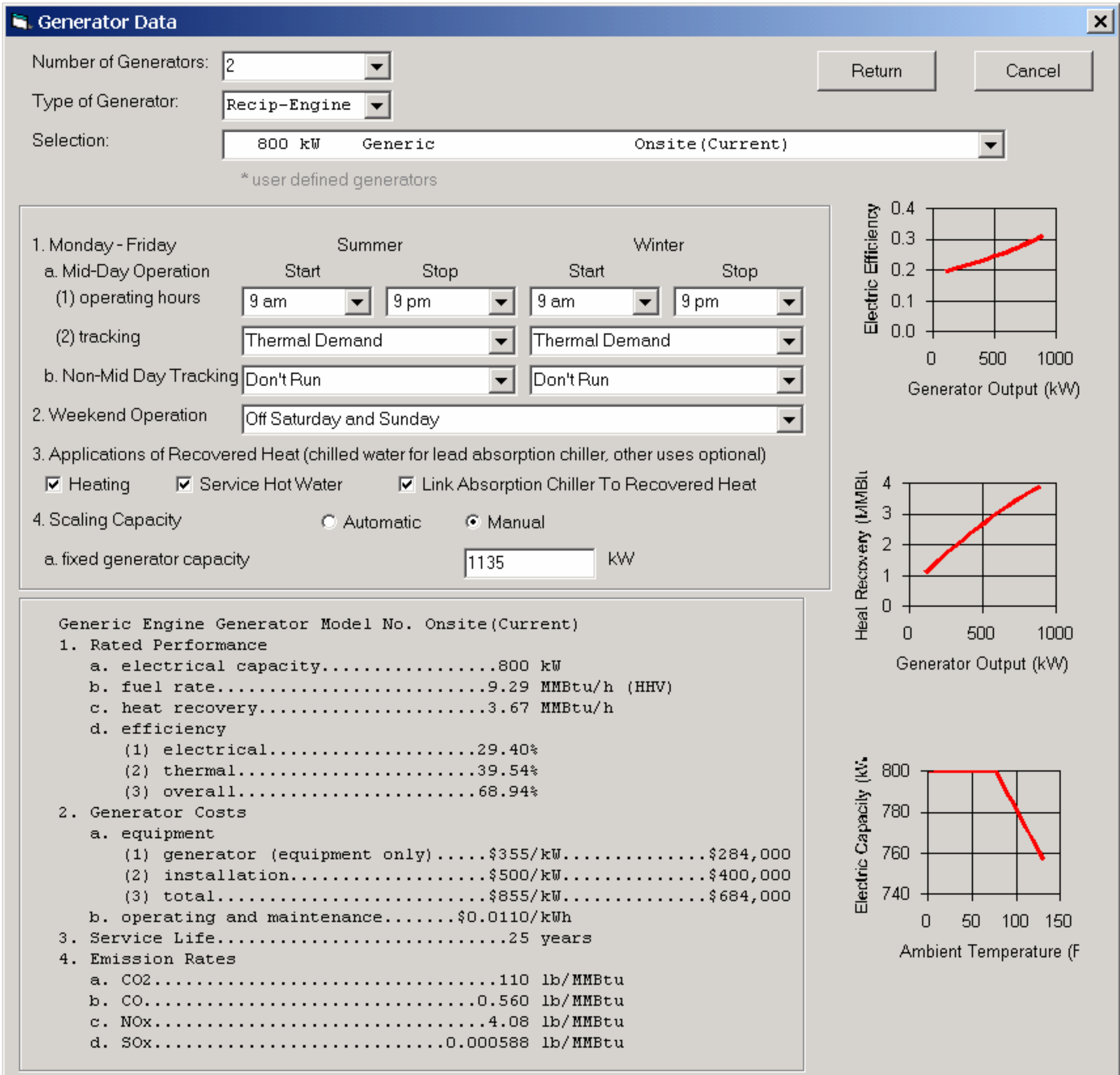


Fig. 4. Generator data selection form for alternative user data entry.

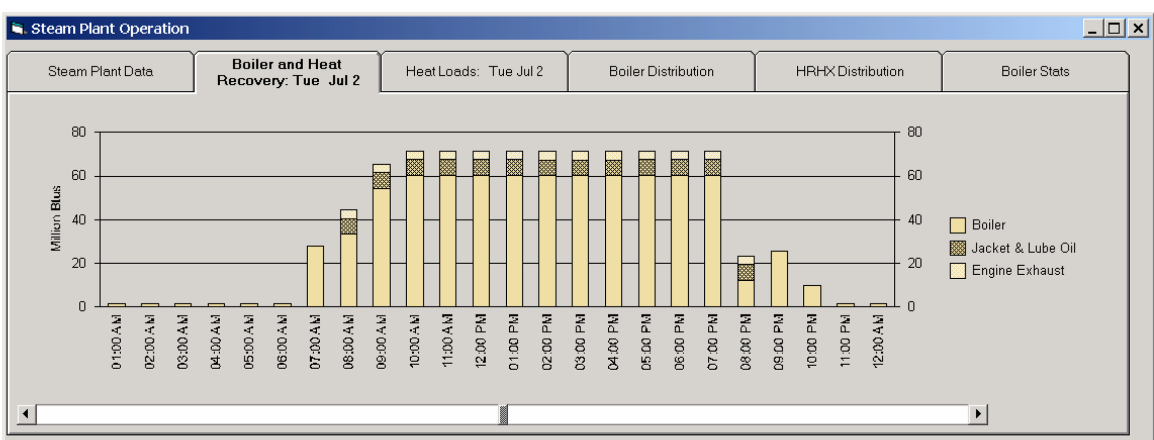


Fig. 5. Scrolling bar chart of boiler and heat recovery heat exchanger output.

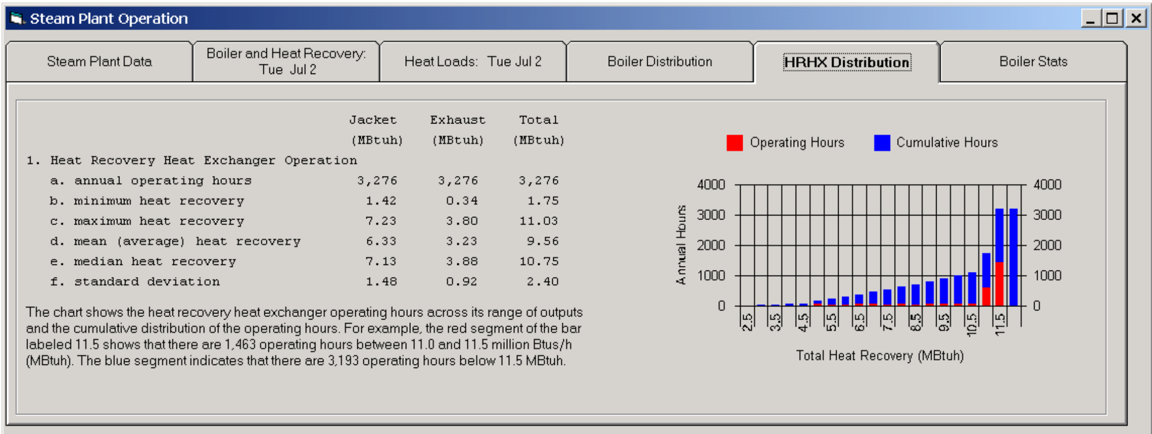
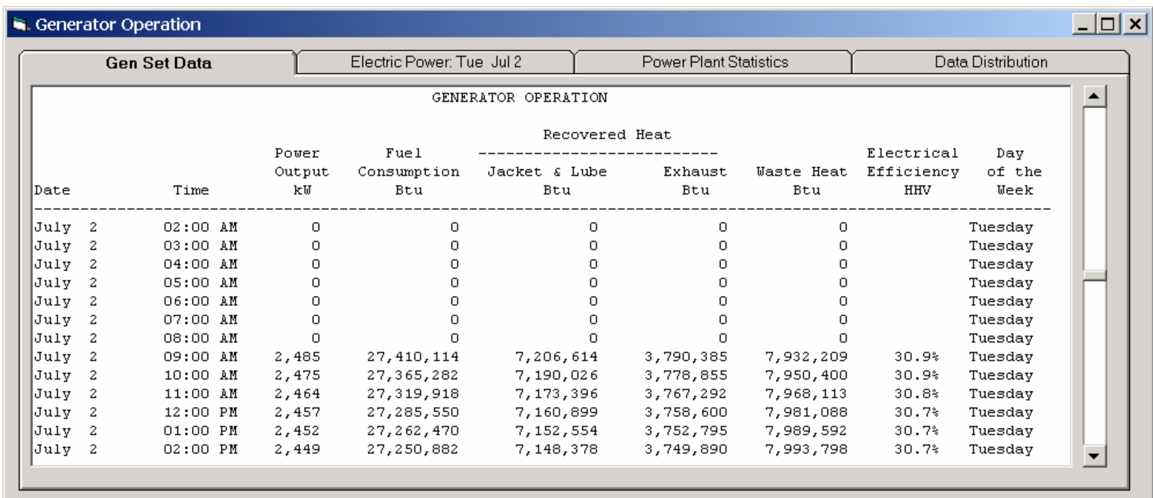


Fig. 6. Distributions of heat recovery heat exchanger loads.



Date	Time	Power Output kW	Fuel Consumption Btu	Recovered Heat: Jacket & Lube Btu	Recovered Heat: Exhaust Btu	Waste Heat Btu	Electrical Efficiency HHV	Day of the Week
July 2	02:00 AM	0	0	0	0	0		Tuesday
July 2	03:00 AM	0	0	0	0	0		Tuesday
July 2	04:00 AM	0	0	0	0	0		Tuesday
July 2	05:00 AM	0	0	0	0	0		Tuesday
July 2	06:00 AM	0	0	0	0	0		Tuesday
July 2	07:00 AM	0	0	0	0	0		Tuesday
July 2	08:00 AM	0	0	0	0	0		Tuesday
July 2	09:00 AM	2,485	27,410,114	7,206,614	3,790,385	7,932,209	30.9%	Tuesday
July 2	10:00 AM	2,475	27,365,282	7,190,026	3,778,855	7,950,400	30.9%	Tuesday
July 2	11:00 AM	2,464	27,319,918	7,173,396	3,767,292	7,968,113	30.8%	Tuesday
July 2	12:00 PM	2,457	27,285,550	7,160,899	3,758,600	7,981,088	30.7%	Tuesday
July 2	01:00 PM	2,452	27,262,470	7,152,554	3,752,795	7,989,592	30.7%	Tuesday
July 2	02:00 PM	2,449	27,250,882	7,148,378	3,749,890	7,993,798	30.7%	Tuesday

Fig. 7. Scrolling table of hourly generator operation.

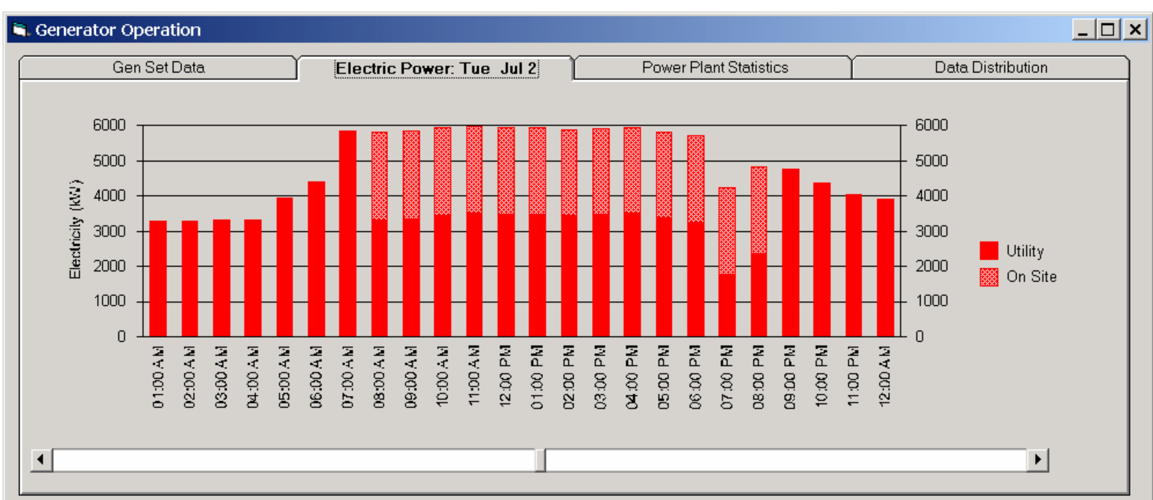


Fig. 8. Scrolling bar chart of hourly utility power and on site power generation.

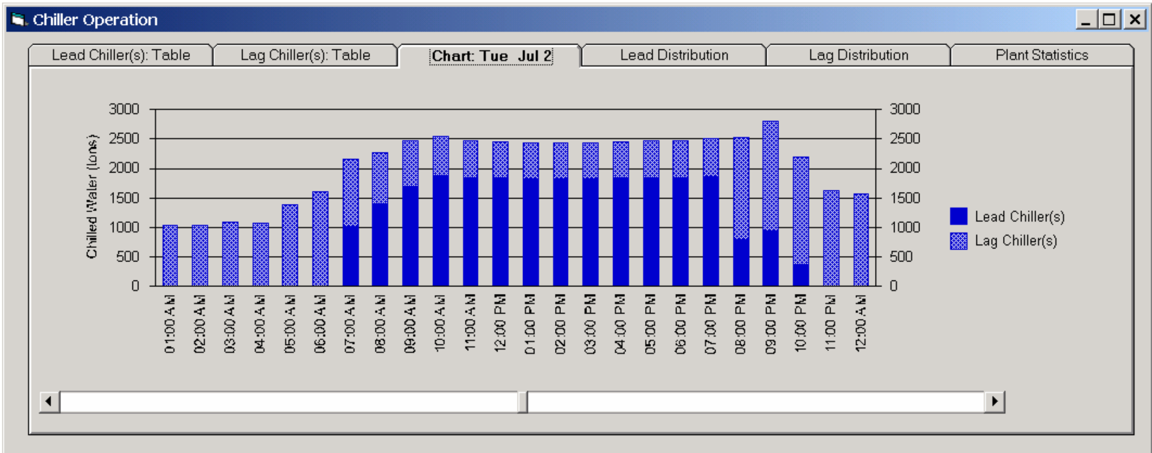


Fig. 9. Scrolling bar chart of lead (absorption) and lag (electric) chiller outputs.