PLANT

Introduction

The PLANT program translates the energy supplied to space heating and cooling equipment into the energy actually consumed by boilers, chillers, pumps, engines, etc. It sums the hourly demands of the electricity used by lights, fans, and equipment and of the fuel used by boilers and engines. It also accounts for any heat recovered. From these totals it generates reports on monthly and yearly usage.

For each hour simulated the following information is passed from SYSTEMS to PLANT:

For Boilers, Chiller, Electric Utility or Total Energy Plant

Heating Load in Btu/hr
Cooling Load in Btu/hr
Electric Load in kW
Hot water in Btu/hr
Gas in Btu/hr
Oil in Btu/hr

} As modified by SYSTEMS

For Cooling Tower Simulation

Ambient air temperature in °F
Humidity ratio in lb water/lb dry air

Utility usage is based on a conversion factor called SOURCE–SITE–EFF; it reflects the energy consumed at the source used to create the utility-supplied energy. All energy conversions are based on actual curve fits of representative equipment. You should examine the default parameters to be sure that they represent the equipment you want to simulate.

Suggested Sequence of PLANT Program Input

First enter an

INPUT PLANT ..

instruction. Next, describe each piece of equipment (boiler, chiller, cooling tower, etc.) in the plant using a

PLANT–EQUIPMENT

instruction. The following instructions may then be entered as desired or required:

PART–LOAD–RATIO
PLANT–PARAMETERS
HEAT–RECOVERY
ENERGY–RESOURCE

After the keywords and values required by the above instructions are specified, an END instruction is entered to indicate that the input data is finished; finally, an instruction is entered that tells the PLANT program to perform the desired computations:

END ..
COMPUTE PLANT ..

In the following, you will find:

- A description of each type of plant equipment.
- A sample input for each type of equipment. For trial purposes, these inputs can be used to replace the PLANT input on p.B.11 (Appendix B).
- A list of other capabilities for each type of equipment.

Description of ELEC–STM–BOILER

The electric boiler in DOE-2 is a multi-staged electric resistance unit. The default condition is no electricity use for feed water or condensate pumps. Suggested minimal input for ELEC–STM–BOILER is:

```
STM-B = PLANT-EQUIPMENT
        TYPE = ELEC-STM-BOILER
        SIZE = -999   ..
```

Note that SIZE = -999 will cause the program to automatically size the boiler based on the peak demand calculated by SYSTEMS.

Additional Capabilities for ELEC–STM–BOILER:

1. To simulate additional electricity use for feed water or condensate pumps, insert the command

```
PART-LOAD-RATIO  TYPE  = ELEC-STM-BOILER
                 E-I-R = 1.05   ..
```

This provides a 5% additional electric requirement for pumping, which is assumed to vary proportionately to the load on the boiler.

Description of STM–BOILER

The steam boiler in DOE-2 is gas-fired with an induced draft fan. The default for the combined electricity use of the power burner and draft fan is 2.2% of the boiler size. Suggested minimal input for STM–BOILER is as follows:

```
STM-B = PLANT-EQUIPMENT
        TYPE = STM-BOILER
        SIZE = -999   ..
```

Additional Capabilities for STM–BOILER:

1. To simulate an oil-fired rather than a gas-fired boiler, insert the command:

```
ENERGY-RESOURCE  RESOURCE = FUEL-OIL ..
```

2. To simulate additional electricity use for feed water or condensate pumps, refer to the "Additional Capabilities for ELEC–STM–BOILER" above.

Description of HW–BOILER

The hot water boiler is also referred to as a hot water generator. It is a gas-fired unit with a default of 2.2% added electric for power burner and an induced draft fan. A hot water recirculating pump is automatically included by the program and is sized to the system peak. Suggested minimal input for HW–BOILER is as follows:

```
HWG = PLANT-EQUIPMENT
      TYPE = HW-BOILER
      SIZE = -999   ..
```

Additional Capabilities for HW-BOILER:

1. To simulate a unit without a power gas burner and induced draft fan, insert:

   PART-LOAD-RATIO TYPE = HW-BOILER E-I-R = 0 ..

2. To change either the pumping requirements or the efficiency of the burner, there are a number of keywords to use:

PLANT-PARAMETERS	HCIRC-SIZE-OPT	= INST-PLANT-EQUIP
	HCIRC-PUMP-TYPE	= VARIABLE-SPEED
	HCIRC-DESIGN-T-DROP	= value desired
	HCIRC-HEAD	= value desired
	BOILER-HIR	= 1.25 .. $1/efficiency

Description of ELEC-HW-BOILER

The electric hot water boiler is a multi-stage electric resistance hot water generator with a hot water pump. See HW-BOILER.

Description of ABSOR1-CHLR

The one-stage absorption chiller in DOE-2 is a unit that can be supplied by either 12-lb steam or 240°F water. The solution pumps for the unit require only 0.4% additional electric energy based on the size of the unit. A chilled water pump is called automatically and sized on the peak system requirement. You must input either a steam boiler, a hot water boiler, or district steam to supply heat to drive the absorption chiller. A cooling tower is also called automatically; you can input it if you want, but you are cautioned not to input either the size or the number of units. Suggested minimal input for ABSOR1-CHLR is as follows:

```
AB-CHLR = PLANT-EQUIPMENT
          TYPE = ABSOR1-CHLR
          SIZE = -999   ..
```

Additional Capabilities for ABSOR1-CHLR:

1. To increase the electric requirements for solution pumps insert:

   PART-LOAD-RATIO TYPE = ABSOR1-CHLR
                    E-I-R = value desired

2. To input a cooling tower explicitly, insert:

```
CTOW = PLANT-EQUIPMENT
       TYPE = COOLING-TWR
       SIZE = -999   ..
```

   We suggest you *not* enter the size of the tower; in DOE-2, size refers to the tower cell size and INSTALLED-NUMBER refers to the number of cells.

3. To change the pumping requirements to suit specific project needs, use PLANT-PARAMETERS:

```
PLANT-PARAMETERS    CHILL-WTR-T           = value desired
                    ABSOR1-HIR            = .66 is default, but old
                                            units may have degraded
                                            to as low as .4
                    TWR-SETPT-CTRL        = FIXED or WETBULB-RESET
                    TWR-SETPT-T           = value desired
                                            (use if FIXED selected)
                    TWR-DESIGN-WETBULB    = value desired
                    TWR-PUMP-HEAD         = value desired
                                            (condenser water pump)
                    CCIRC-DESIGN-T-DROP   = value desired
                    CCIRC-HEAD            = value desired
                    CCIRC-SIZE-OPT        = INST-PLANT-EQUIP
                    CCIRC-PUMP-TYPE       = VARIABLE-SPEED    ..
```

4. To supply steam to the building for space heating or for the absorption chiller from a district steam (or hot water) system, use:

```
ENERGY-RESOURCE    RESOURCE = STEAM  ..
```

Description of ABSOR2-CHLR

The two-stage absorption chiller in DOE-2 is the same as the one-stage chiller (ABSOR1-CHLR), except that it operates with 125-lb steam or 400°F hot water. The electric requirement for solution pumps in 0.7% of the unit size. All of the additional capabilities described for the ABSOR1-CHLR also apply here. Suggested minimal input for ABSOR2-CHLR is:

```
AB2-CHLR = PLANT-EQUIPMENT    TYPE = ABSOR2-CHLR
                              SIZE = -999 ..
```

Description of ABSORG-CHLR

The direct gas-fired absorption chiller can also operate as a hot water generator. Therefore, all accessories (such as the cooling tower, chilled water pump, condenser water pump, and hot water pump) are called. The solution pumps default to 0.7% of the unit size since this, too, is a two-stage unit. All of the additional capabilities described for ABSOR1-CHLR apply, with the following additions:

```
PLANT-PARAMETERS    ABSORG-HIR          = value desired (1.0 is default)
                    ABSORG-HEAT-XEFF    = value desired for the HWG
                                          efficiency (decimal fraction) ..
```

Description of HERM-CENT-CHLR

The hermetic centrifugal chiller in DOE-2 has a default COP of 4.55 and a KW/Ton of .77, which makes it a very conservatively rated unit for present day practice. The cooling tower, condenser water pump, and chilled water pump are all called by default; however, you can modify the selection of these auxiliaries by using the keywords described for ABSOR1-CHLR. Suggested minimal input for HERM-CENT-CHLR is as follows:

```
CHL = PLANT-EQUIPMENT    TYPE = HERM-CENT-CHLR    SIZE = -999 ..
```

Additional Capabilities for HERM-CENT-CHLR:

1. To change to an air-cooled condenser, specify:

```
PLANT-PARAMETERS    HERM-CENT-COND-TYPE = AIR    ..
```

2. To change the COP of the unit to 5.0 (0.7 KW/Ton), set ELEC-INPUT-RATIO, which is the inverse of COP, as follows:

```
PART-LOAD-RATIO    TYPE = HERM-CENT-CHLR    E-I-R = .2    ..
```

Description of HERM-REC-CHLR

The hermetic reciprocating chiller in DOE-2 is a unit characteristic of multi-compressor or unloading compressor types. It has a default COP of 3.65 or a KW/Ton of .96, which is still reasonable for today. You can change the unit to an air-cooled condenser (the default is a cooling tower with condenser water pump) and chilled water pump. The unit can be modified as described for ABSOR1-CHLR. Suggested minimal input for HERM-REC-CHLR is:

```
CHL =    PLANT-EQUIPMENT      TYPE = HERM-REC-CHLR  SIZE = -999 ..
         PLANT-PARAMETERS     HERM-REC-COND-TYPE = AIR    ..
```

Description of DBUN-CHLR

The double bundle chiller in DOE-2 is a centrifugal type chiller with two condenser tube bundles, one of which is piped to the cooling tower and the other piped to the building hot water heating circuit. The unit operates as a straight chiller whenever there is no call for heat and operates as a heat pump to reject heat to the heating circuit up to its maximum capacity; it is then supplemented by a hot water boiler. Suggested minimal input for DBUN-CHLR is:

```
HP-CHLR    = PLANT-EQUIPMENT    TYPE = DBUN-CHLR    SIZE = -999 ..
HWG        = PLANT-EQUIPMENT    TYPE = HW-BOILER    SIZE = -999 ..
```

Additional Capabilities for DBUN-CHLR:

1. In the building heating mode, to change the leaving water temperature from the condenser (default = 105°F), insert:

```
PLANT-PARAMETERS    DBUN-COND-T-REC = value desired    ..
```

2. If there is a chiller other than the double bundle, the program will stage the units to favor the double bundle when heating is required. When entering another chiller, you should size both units, since the program doesn't know what split is required.

```
CHLR = PLANT-EQUIPMENT    TYPE = HERM-CENT-CHLR
                          SIZE = value (millions of Btu/hr)    ..
```

Description of ENG-CHLR

The gas engine chiller in DOE-2 is a nominal 150-ton twin screw compressor chiller driven by a modified diesel engine. The unit capacity is controlled by varying the speed of the engine to

meet the building load; it has a default evaporator/engine COP of 1.4. It is possible to recover heat from the engine to satisfy space heating loads and/or provide service hot water. The unit defaults to cooling tower but can also be air-cooled. Suggested minimal input for ENG–CHLR is as follows:

```
ECHL = PLANT-EQUIPMENT    TYPE = ENG-CHLR    SIZE = -999 ..
```

Additional Capabilities for ENG–CHLR:

1. To recover heat from the engine for both space heat and service hot water, insert:

```
HEAT-RECOVERY    SUPPLY-1 = (ENG-CHLR)
                 DEMAND-1 = (SPACE-HEAT,PROCESS-HEAT) ..
```

2. To change the unit to air-cooled, insert:

```
PLANT-PARAMETERS    ENG-CH-COND-TYPE = AIR ..
```

Description of COOLING–TWR

The cooling tower in DOE-2 is an induced draft tower with a propeller type fan at the top. There are numerous plant parameters that allow you to modify the design wet bulb temperature and to satisfy other specific requirements. Most users do not input the tower because DOE-2 automatically calls for one and sizes it whenever one is needed. However, the default design wet bulb is 78°F, which is acceptable for some locations but not all. Suggested minimal input for COOLING–TWR is as follows:

```
CTW = PLANT-EQUIPMENT    TYPE = COOLING-TWR    SIZE = -999 ..
```

Additional Capabilities for COOLING–TWR:

1. To change the design wet bulb, insert:

```
PLANT-PARAMETERS    TWR-DESIGN-WETBULB = value desired ..
```

2. To change from a one-speed fan (the default) to a multiple-speed fan, insert:

```
PLANT-PARAMETERS    TWR-CAP-CTRL = TWO-SPEED-FAN ..
or
PLANT-PARAMETERS    TWR-CAP-CTRL = VARIABLE-SPEED-FAN ..
```

Description of DHW–HEATER and ELEC–HEATER

The service hot water heaters in DOE-2 are standard units. The DHW–HEATER is gas fired (default). There is no pumping assigned to either unit type, but you can use the PART-LOAD-RATIO command to assign pumping if desired. If you want to recover waste heat (previously demonstrated for ENG–CHLR), a hot water heater must not be entered because it locks out recovery. Also, to simulate an indirect exchanger inside the hot water generator for service hot water heating, a hot water heater should not be entered.

Description of PLANT Input Instructions

Limitation on the Number of Commands

The maximum allowable number of PLANT instructions for specifying required PLANT data is as follows:

Instruction	Maximum Number
ENERGY-RESOURCE	7
HEAT-RECOVERY	1
PLANT-ASSIGNMENT	1
PLANT-EQUIPMENT	60
PLANT-PARAMETERS	1
PLANT-REPORT	1 command
TITLE	5
u-names	118

PLANT-EQUIPMENT

This command tells the PDL that the following data specifies plant equipment. If at least one PLANT-EQUIPMENT instruction is not entered, then the PLANT program generates an error message.

u-name — is not required but is advisable in order to identify equipment in reports.

TYPE — is the type of equipment to be used. See Table 4.1 for allowed code-words.

SIZE — is the nominal rated output capacity, expressed in units of one million Btu's per hour (MBtu/hr), for the item of equipment being specified. For example, a 100-ton chiller should be specified as SIZE = 1.20 since the conversion factor is 12,000 Btu/hr per ton. A ten million Btu/hr boiler is specified as SIZE = 10.0.

If SIZE = −999 is entered, PLANT automatically sizes, in accordance with peak load, the following types of equipment: all boilers, chillers, towers, and diesel and gas electric generators. Steam turbine generators will not be automatically sized.

Hot water and chilled water circulation pumps are **always** automatically sized by the PLANT program. The flow rate, electrical power, and heat gain are calculated from the values of PLANT-PARAMETERS keywords as follows:

Flow Rate: $GPM_p = \frac{\text{Design-Load}}{\text{X-DESIGN-T-DROP x 60 min/h x 8.34 Btu/gallon-}^{\circ}\text{F}}$

Power: $Elect_p = \frac{\text{X-HEAD x } GPM_p \text{ x 0.643 Btu-min/ft-gallon-hr}}{\text{X-MOTOR-EFF x X-IMPELLER-EFF}}$

Heat Gain: $Gain_p = (\text{Design-Load x X-LOSS}) + (Elect_p \text{ x X-MOTOR-EFF})$

INSTALLED–NUMBER — is the total number of units of the type and size previously specified. As an example, if three 100-ton chillers have been specified, enter INSTALLED–NUMBER = 3.

Note: input the actual sizes and number of equipment when known (such as in retrofit studies) in order to improve the accuracy of the simulation.

TABLE 4.1

TYPE Code-Words for PLANT–EQUIPMENT

Equipment	Code-Word
Heating	
Electric boiler	ELEC–STM–BOILER
Steam boiler	STM–BOILER
Hot-water boiler	HW–BOILER
Electric hot-water boiler	ELEC–HW–BOILER
Cooling	
One-stage absorption chiller	ABSOR1–CHLR
Two-stage absorption chiller with economizer	ABSOR2–CHLR
Absorption chiller/HWG (gas fired)	ABSORG–CHLR
Hermetic centrifugal compression chiller	HERM–CENT–CHLR
Hermetic reciprocating compression chiller	HERM–REC–CHLR
Double bundle chiller	DBUN–CHLR
Cooling tower	COOLING–TWR
Gas Engine driven reciprocating chiller	ENG–CHLR
Domestic Hot Water*	
Domestic hot-water heater	DHW–HEATER
Electric domestic hot-water heater	ELEC–DHW–HEATER

* If a domestic hot water heater is not input, hot water loads input in SYSTEMS through the PLANT–ASSIGNMENT instruction or through the SOURCE–BTU/HR keyword in the (LOADS) SPACE–CONDITIONS subcommand will be passed to other heating equipment. If no heating equipment is defined, the domestic hot water demand will appear as a load not met.

PLANT–ASSIGNMENT

PLANT–ASSIGNMENT identifies the HVAC system or systems supported by PLANT. The instruction has the form

u-name = PLANT–ASSIGNMENT ..

where u-name is the name of the corresponding PLANT–ASSIGNMENT instruction defined in the SYSTEMS program input.

PART–LOAD–RATIO

The equipment PART–LOAD–RATIO instruction specifies the nominal electric power input ratio to operate the equipment and/or supporting electric auxiliaries. PART–LOAD–RATIO tells the PLANT processor that the data to follow are related to the part-load operation of a specific type of equipment.

TYPE — is the code-word selected from Table 4.1 that identifies the type of equipment that applies to the part-load ratios specified. Only one TYPE may be specified per instruction.

ELEC–INPUT–RATIO — The electric input to nominal capacity ratio is expressed as

$$\text{ratio} = \frac{\text{electric power input to electric auxiliaries (Btu/hr)}}{\text{nominal capacity of equipment being defined (Btu/hr)}}$$

or

ratio = 1/COP for refrigeration machines

See Table 4.2 for default values.

This entry should include the electric power to move and control the working fluid flowing through the equipment plus the primary power input to the equipment itself. For an absorption refrigeration chiller, the electric power input to the solution pump must be considered. Similarly, for a fossil-fueled boiler, the electric power input to the boiler draft fan and power burners must be considered. However, when defining the ELEC–INPUT–RATIO for this equipment, you should realize that the electric power delivered to the hot, chilled, and condenser water pumps is calculated separately and size and capacities are controlled through PLANT–PARAMETER keywords. This is also true for cooling tower fans.

TABLE 4.2

Equipment PART-LOAD-RATIO Default Values

TYPE Code-Word		Electric Input to Nominal Capacity
Heating Equipment		(default)
ELEC-STM-BOILER	Electric boiler	1.000
STM-BOILER	Steam boiler	0.022
HW-BOILER	Hot water boiler	0.022
ELEC-HW-BOILER	Electric hot water boiler	1.000
Cooling Equipment		
ABSOR1-CHLR	One-stage absorption chiller	0.004
ABSOR2-CHLR	Two-stage absorption chiller w/economizer	0.0071
ABSORG-CHLR	Gas-driven absorption chiller	0.0071
HERM-CENT-CHLR	Hermetic centrifugal chiller	0.220
HERM-REC-CHLR	Hermetic reciprocating chiller	0.274
DBUN-CHLR	Double-bundle chiller	0.220
ENG-CHLR	Twin screw compressor chiller	0.0053
Domestic Hot Water		
DHW-HEATER	Water heater	0.000
ELEC-DHW-HEATER	Electric water heater	1.000

[Table revised 11/91]