

# Overview of DOE-2.2

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# Introduction

This report is an overview of the new features DOE-2 building energy analysis program as implemented in the up-coming DOE-2.2 version.

DOE-2.2 was developed in a collaborative effort between Lawrence Berkeley National Laboratory and James J. Hirsch & Associates, with major support from the U.S. Department of Energy (program manager Dru Crawley) and the Electric Power Research Institute (program manager Wayne Krill). DOE-2.2 is based on DOE-2.1E, which was released in 1994. The main goals of the DOE-2.2 project were: (1) to make some basic improvements to the simulation portions of the program; and (2) to make the Building Description Language (BDL) processor more capable of being used in an interactive environment. The new capabilities of DOE-2.2 will provide more accurate and flexible simulation of window, lighting, and HVAC systems, and will allow integration with interactive user interfaces.

## Sponsors and Developers

Major support for development of DOE-2.2 was provided by the U.S. Department of Energy (DOE; Dru Crawley, program manager), the Electric Power Research Institute (EPRI; Wayne Krill, program manager), and James J. Hirsch & Associates (JJH). Additional support was provided Southern California Edison, Bonneville Power Administration, California Institute for Energy Efficiency, Duke Power, Pacific Gas & Electric Company, Philadelphia Electric Company, Southern Company, a consortium of California Gas and Electric Utilities with the California Energy Commission (CCIG), Pacific Power, and the British Columbia Buildings Corporation.

The major developers of DOE-2.2 were Lawrence Berkeley National Laboratory (LBNL) and James J. Hirsch & Associates (and their subcontractors Steven D. Gates Engineering, Scott A. Criswell Software, Partnership for Resource Conservation, Marlin S. Addison). Also contributing to the development were the Swiss Federal Laboratory for Materials Testing and Research (EMPA) and the University of Karlsruhe. LBNL and JJH jointly developed the new BDL language and overall program structure. LBNL, EMPA, and UK collaborated on the new LOADS features. JJH developed the new HVAC and ECONOMICS programs.

## Availability

It is anticipated that source, object, distribution, and derivative works licenses for DOE-2.2 will be available from LBNL and JJH. Arrangements can be made with the licensor to provide support and guidance for modifying DOE-2.2. As of this time, the details of the licenses that will be available—such as cost, royalties and terms and conditions—have not yet been finalized.

## Documentation and Users News

Initial DOE-2.2 documentation will consist of a *DOE-2.2 Basics Manual*, a *DOE-2.2 Command/Keyword Dictionary* and a *DOE-2.2 Topics Manual*.

- The *Basics Manual* is a revision of the *DOE-2.1E Basics Manual*; it describes the most commonly used features of DOE-2 and is aimed at new users.
- The *Command/Keyword Dictionary* describes all of the commands and keywords of the DOE-2.2 input language and describes all of the output reports. It is based on the previous *DOE-2.1A Reference Manual*, *DOE-2.1E Supplement* and *DOE-2.1E BDL Summary*, with addition of new commands and keywords. (The *BDL Summary* will no longer be printed; its information will be included in the *Command/Keyword Dictionary*).

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- The *Topics Manual* gives guidance on effective use of DOE-2.2 by simulation topic, such as “Daylighting” or “Equipment Sizing.”

Instructions will be available for converting DOE-2.1E inputs to DOE-2.2 (DOE-2.2 is *not* upwardly compatible with DOE-2.1E). In addition, we will provide instructions on bringing up DOE-2.2 on various computer platforms.

The *Sample Run Book* will no longer be printed; instead, sample inputs and outputs will be available in electronic form.

LBNL will continue to publish the *Building Energy Simulation User News*. The *User News* contains articles of interest to DOE-2.2 users, describes program fixes and enhancements, provides information on obtaining DOE-2.2 and its derivatives, and lists DOE-2.2 related services. You can view the *User News* on the World-Wide Web at <http://eande.lbl.gov/BTP/SRG/UNews/>.

## Further Information

For further information on DOE-2.2 contact:

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## DOE-2.2 Changes and New Features

The following changes and additions are relative to DOE-2.1E version 087 (December 12, 1995). DOE-2.1E version 087 itself consists of the original release version of DOE-2.1E (version 002, November 1993) plus the following enhancements: natural ventilation capability in all single-duct system types; an enhanced residential system with forced ventilation; inside surface temperature calculation; and additional daylighting controls. Further information on differences between DOE-2.2 and DOE-2.1E input can be found in "Converting DOE-2.1E Input Files for Use with DOE-2.2," which will be made available on request.

### DOE-2.2 Flow

Figure 1 shows the major subprograms and files of DOE-2.2 and how they are connected. Two important structural differences from DOE-2.1E are (1) SYSTEMS and PLANT have been combined into a single program called "HVAC"; (2) LOADS and HVAC are calculated together in single time step loop followed by ECONOMICS, if UTILITY-RATEs are specified, whereas previously, LOADS was calculated for the run period, then SYSTEMS, then PLANT, then ECONOMICS.

## Building Description Language (BDL) Changes

### Name Lengths

Previously, the maximum length of a DOE-2 symbol (command, keyword, or name) was 16 characters. Now, all symbols can be up to 32 characters. This means U-names (a user assigned name for a building element) can be up to 32 characters long; the entire 32 character names must be used in all places. Also, when specifying commands, keywords, and codewords, the use of more than 16 character as the name may cause the item not to be recognized; previously, characters after the 16<sup>th</sup> were ignored, now characters after the 32<sup>nd</sup> are ignored.

### TYPE keyword

There is a new class of commands in DOE-2.2; TYPE commands. These commands require TYPE as the first keyword in the input for a command; TYPE accepts a codeword value which is used to designate the keywords and defaults that are to be utilized for the object being defined. The TYPE keyword was created to solve a problem with DOE-2's building description. Generally, a DOE-2 command corresponds to a building or system component (object). For instance, a WINDOW command describes a window and the SYSTEM command describes an HVAC system. But in many cases this classification is not detailed enough. There are many different kinds of HVAC system, and the input needed to describe them may differ greatly from system to system. In DOE-2.1 this situation was handled on an ad hoc basis command by command. For the SYSTEM command, for instance, the SYSTEM-TYPE keyword was used to specify the type of system desired, and a special table was used to describe which keywords were allowed for a given system, and what the defaults would be. DOE-2.2 recognizes that this situation is quite general: there is often a need to subclassify building and system components. The TYPE keyword allows the DOE-2.2 developers to specify type dependent keywords and defaults in a general way when needed. Most HVAC commands are TYPE commands; many LOADS commands will be TYPE commands.

*Example:* "Flr:1 > North Zone" = ZONE      TYPE = CONDITIONED

# DOE-2.2 Flow

(shaded boxes are programs)

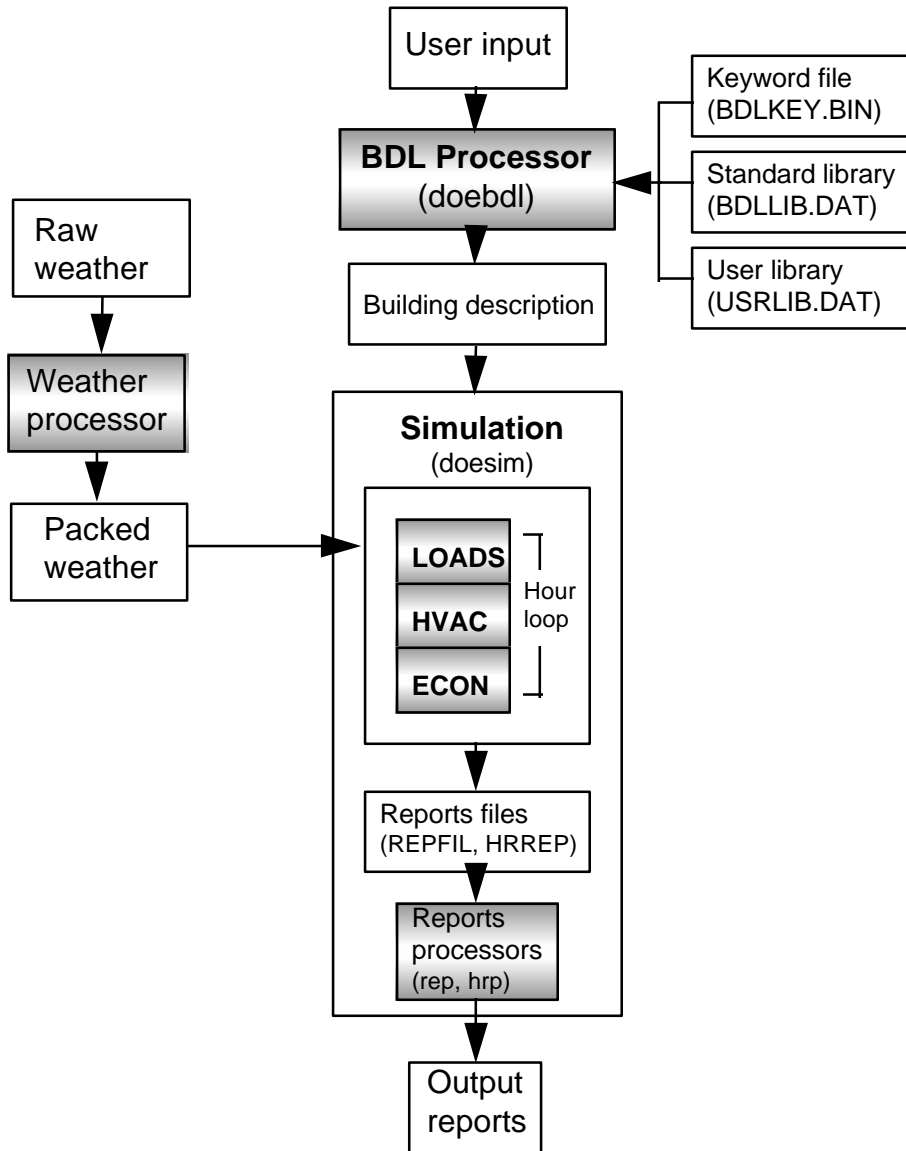


Figure 1: DOE-2.2 program flow

### Expressions

In DOE-2.2, keywords can be assigned an *expression* as well as a fixed value. Expressions differ from the DOE-2 macro capability in that they operate on actual keyword values rather than manipulate text. The expressions can contain the usual arithmetic and logical operators plus a list of standard mathematical functions. If-else and switch statements are also allowed. For a particular command and keyword, an expression can use the value of any PARAMETER, local or global command keyword (keyword belonging to this command), keyword of any command referenced by this command (this referencing can be nested), keyword of the parent command, or keyword of any command referenced by the parent command (this referencing can also be nested). A parent command is the command of the building element to which the element being described belongs or is attached. For example, the parent of a window would be the wall containing the window; the parent of a wall would be the space containing the wall, and so forth. A global command is SITE-PARAMETERS, BUILD-PARAMETERS, or MASTER-METERS.

An expression is comprised of a single statement and will return a single value. The expression syntax is compatible with the conventions defined in both the C and FORTRAN programming languages.

An expression is placed into DOE-2's BDL input for a component definition command, or a SET-DEFAULT command, keyword within curly brackets (i.e., { ... }). Expressions can include elements such as special BDL functions, math and logical operators, and logical structures, that can be used to create complex relations that are dynamically evaluated into the value for a keyword. Expressions are fully BDL read or write compatible within PowerDOE and are saved in the BDL memory structure during execution, and thus can be created, edited, or deleted from within the PowerDOE interface.

Although manual entry of BDL expressions requires a fairly detailed knowledge of the BDL data structure, the *PowerDOE* Expressions interface allows you to define expressions using a generic and intuitive syntax. The expression syntax includes the following operators and functions:

Operators	Mathematical, logical, and bitwise operators
Standard functions	Standard mathematical, trigonometric, and logarithmic functions
BDL functions	Use these functions to obtain information from BDL objects.
If-then statements	Use for making expression output based on the evaluation of some other expression.
Switch statements	Use for keying expression output on an integer value of some other expression
Special keywords	Use the UNDEFINED/UNUSED/NODEFAULT keywords to convey special BDL meanings
Comments	You can add comments to an expression.

### Arithmetic Operators

These operators are used to perform arithmetic operations on constants or variables.

- \* Multiplication
- / Division
- + Addition
- Subtraction (or Unary Minus)
- % Remainder (mod)
- \*\* Exponential

### Logical Operators

These operators are used to perform logical operations on constants or variables.

or .OR.	Or
&& or .AND.	And
! or .NOT.	Not
== or .EQ.	Equal
!= or .NE.	Not equal
> or .GT.	Greater than
< or .LT.	Less than
>= or .GE.	Greater than or equal to
<= or .LE.	Less than or equal to

### Bitwise Operators

These operators are used to query the bits of a byte or a word. They require a more detailed knowledge of the inner workings of PowerDOE and will typically only be used by very advanced users.

&	And
	Or
^	Exclusive or

### Standard Functions

ABS	Returns the absolute value of a number
ACOS	Returns the arccosine of a number
ASIN	Returns the arcsine of a number
ATAN	Returns the arctangent of a number
COS	Returns the cosine of the given angle
EXP	Returns the value of e raised to the power of a given number
FTOA	Converts a floating point number to a character string
INT	Returns the nearest integer value of a number
LOG	Returns the natural logarithm of a number
LOG10	Returns the base-10 logarithm of a number
MAX	Returns the largest value of two numbers
MIN	Returns the smallest value of two numbers
POW	Returns the result of a number raised to a power
SIN	Returns the sine of the given angle
SQRT	Returns the positive square root of number
TAN	Returns the tangent of the given angle

### BDL Functions

Error or #E	Registers a BDL error. No return value.
Global or #G	Returns the value of a BDL <u>global</u> command/keyword.
Local or #L	Returns the value of a <u>local</u> keyword.
LocalRef or #LR	Returns the value of a <u>local</u> keyword referenced by BDL symbol table index.
Parameter or #PA	Returns the value of a BDL-defined PARAMETER given its text string.
Parent or #P	Returns the value of a <u>parent</u> keyword.
ParentRef or #PR	Returns the value of a <u>parent</u> keyword referenced by BDL symbol table index.
RefIndex or #RI	Returns the BDL symbol table index for the symbol which this expression defines.
SymIndex or #SI	Returns the BDL symbol table index for a given <u>symbol</u> .
SymValue or #SV	Returns the BDL symbol table index of the symbol in the given BDL symbol table entry position.

### Executable Statements

If-Then statement



```
if (expression1) then statement1
else if (expression2) then
    statement2
else
    statement3
endif
endif
```

where

*(expression#)* are expressions get evaluated to TRUE or FALSE

*(statement#)* is the statement that is executed based on the evaluation of expression#

Switch statement

```
switch (expression)
    case (const1)           : (expression1)
    case (const2)           : (expression2)
    default                 : (expression3)
endswitch
```

where

*(expression)* is some expression that evaluates to an integer-compatible value.

*(const#)* where # is a possible integer value of *(expression)*

*(expression#)* is the expression that applies whenever *(expression)* evaluates to *(const#)*

**default** is the expression that applies whenever *(expression)* evaluates to a value for which there is no defined **case**.

A simple example of an expression would be:

```
WIN-1 = WINDOW
      X=8  Y=2  H=5  W={1.5*Local("HEIGHT")}
      G-T=GT-WIN-1  FRAME-WIDTH=.25 ..
```

Here "Local" is a BDL function that returns the values of the specified keyword (in this case HEIGHT) of the present object (instance of a command).

A description of the expression syntax, "DOE-2.2 Expression Summary," will be made available on request.

## DOE-2.2 Library

In DOE-2.1E and previous versions of DOE-2 only three kinds of data could be stored in the library: data defining a MATERIAL command, wall response factors, and room weighting factors. The library consisted of a binary file, and it was not particularly convenient to examine or change it. In DOE-2.2 the library is a text file containing BDL "objects"; data for most BDL commands can be stored in the library. The format resembles that of a BDL command and keywords.

The data for a library entry begins with a line starting with "\$LIBRARY-ENTRY" followed by the entry name (32 characters maximum), followed by the command name for the entry starting in column 48. Next come up to 2 lines of comments, followed by the data in normal BDL <keyword> = <value> free format style. For example, here is the entry for some materials in the DOE-2.2 library:

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---

```
$LIBRARY-ENTRY HF-C9                                MAT
$Common Brick, 8 Inch
  TH=0.6670 COND=0.4200 DENS=120.0 S-H=0.2 ..
$LIBRARY-ENTRY HF-C10                              MAT
$Concrete, Heavy Weight, 8 Inch
  TH=0.6670 COND=1.0000 DENS=140.0 S-H=0.2 ..
```

The standard ASHRAE walls, roofs and ceilings are also in the new library. Example:

```
$LIBRARY-ENTRY ASHW-41                              LA
$2 in. Insulation With 8 In.
$Heavy Weight Concrete
  MAT=(HF-A1,HF-B3,HF-C10,HF-E1) I-F-R=0.685 ..
```

In DOE-2.2 the default HVAC performance curves have been removed from the source code and put in the library. Example:

```
$LIBRARY-ENTRY SDL-C6                                CURVE-FIT
  TYPE=BI-QUADRATIC COEF=( 0.94526330,-0.00941990, 0.00022700,
                           0.00048050,-0.00000450,-0.00005990) ..
```

The separate window library has been eliminated and the definitions of window composition are in the new library. Example:

```
$LIBRARY-ENTRY 2003                                GLASS-TYPE-CODE
$Double Clear 6mm/6mm Air
DESCRIPTION=*Double Clear 6mm/6mm Air              *
NLAYER=2  RBSOL-HEMI=0.182  RBVIS-HEMI=0.227  SHDCOF=0.810
GAPS-FILL=(Air      ,Air      ,Air      ,Air      )
GAPS-THICK=( 6.3, 0.0, 0.0, 0.0)
GAPS-COND=( 0.02410,0.00000,0.00000,0.00000)
GAPS-DCOND=( 7.600, 0.000, 0.000, 0.000)
GAPS-VISC=( 1.730, 0.000, 0.000, 0.000)
GAPS-DVISC=(10.000, 0.000, 0.000, 0.000)
GAPS-DENS=( 1.290, 0.000, 0.000, 0.000)
GAPS-DDENS=(-0.0044, 0.0000, 0.0000, 0.0000)
GAPS-PR=( 0.720, 0.000, 0.000, 0.000)
GAPS-DPR=( 0.00180,0.00000,0.00000,0.00000)
TSOL=
(0.604,0.602,0.598,0.589,0.572,0.540,0.476,0.353,0.155,0.000,0.504)
TVIS=
(0.781,0.781,0.779,0.774,0.761,0.729,0.657,0.505,0.250,0.000,0.678)
ABS-
1=(0.163,0.163,0.166,0.171,0.178,0.187,0.199,0.211,0.211,0.000,0.183)
ABS-
2=(0.120,0.121,0.122,0.125,0.128,0.129,0.126,0.113,0.078,0.000,0.120)
PANES-ID=( 3, 3, 0, 0, 0)
PANES-TIR=(0.000,0.000,0.000,0.000,0.000)
PANES-EMIS-F=(0.840,0.840,0.000,0.000,0.000)
PANES-EMIS-B=(0.840,0.840,0.000,0.000,0.000)
PANES-THICK=(6.000,6.000,0.000,0.000,0.000)
```

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---

```
PANES-COND= ( 150.0, 150.0, 0.0, 0.0, 0.0)
FILMS-COND= (25.47, 3.25, 7.99) U-CENTER= 3.16 ..
```

Note that the above entry is in the format of the new GLASS-TYPE-CODE command which is described elsewhere. All the above items, along with many others, are in the standard library provided with DOE-2.2.

A second library file is available for the user to fill. The user library is always searched first, so it is easy to replace an "official" entry with a new one: simply add it to the user library; there is no need to delete the same entry from the standard library. For instance, putting

```
$LIBRARY-ENTRY SDL-C161 CURVE-FIT
$COIL-BF-FPLR = CONSTANT
TYPE=LINEAR COEF=( 1.00000000, 0.00000000) ..
```

in the user library replaces the old default bypass factor as a function of part load curve with a new default which holds the bypass factor constant.

The user may put almost any kind of item in the library: schedules, walls, windows, even entire HVAC systems. The data for the library entry is moved into the BDL data array after the command in which it was referenced. This data for the referenced library item also appears in the "input echo" section of the program output:

```
* 95 * "Lay Roof" = LAYERS
* 96 * MATERIAL      =("RG02", "BR01", "Mat R19W", "IN23"
* 97 *           , "PW05", "AL33", "AC03")
* 98 * THICKNESS    =(0.083, 0.0313, 0.25, 0.167, 0.0623, 0.35, 0.0623
* 99 *           )
* 100 * ..
* 1 * $Roof Gravel or Slag, 1 Inch
* 2 * TH=0.0833 COND=0.8340 DENS=55.0 S-H=0.4 ..
* 1 * $Built-Up Roofing, 3/8 Inch
* 2 * TH=0.0313 COND=0.0939 DENS=70.0 S-H=0.35 ..
* 1 * $Preformed Mineral Board, 2 Inch,
* 2 * $R-6.9
* 3 * TH=0.1667 COND=0.0240 DENS=15.0 S-H=0.17 ..
* 1 * $Plywood, 3/4 Inch
* 2 * TH=0.0625 COND=0.0667 DENS=34.0 S-H=0.29 ..
* 1 * $Air Layer, 4 Inch or more
* 2 * $Horizontal Roofs
* 3 * RES=0.92 ..
* 1 * $Acoustic Tile, 3/4 Inch
* 2 * TH=0.0625 COND=0.0330 DENS=18.0 S-H=0.32 ..
```

Here the data for library entries RG02, BR01, IN23, PW05, AL33, and AC03 is printed out after the command "Lay Roof" that references them.

## Design Days, Schedules, Run Periods

DOE-2.1E had a clumsy method of assigning run periods to design days. The first run period in the RUN-PERIOD command was assigned to the first design day, and so forth. In addition, the design day command needed information that wasn't easily obtainable. The design day command now looks like:

```
LOSANGELES-CDD = DESIGN-DAY
```

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```
TYPE           =COOLING
DRYBULB-HIGH  =89
DRYBULB-RANGE =20
WETBULB-AT-HIGH =70 ..
```

```
LOSANGELES-HDD = DESIGN-DAY
TYPE           =HEATING
DRYBULB-HIGH  =40
DRYBULB-RANGE =10
WETBULB-AT-HIGH =35 ..
```

The data for heating and cooling design days is easily obtainable from ASHRAE Fundamentals.

The syntax for run periods has changed; it now looks like:

```
RUN-PERIOD-PD
BEGIN-MONTH    =1
BEGIN-DAY      =1
BEGIN-YEAR     =1987
END-MONTH      =1
END-DAY        =31
END-YEAR       =1987
..
```

```
RUN-PERIOD-PD
BEGIN-MONTH    =7
BEGIN-DAY      =1
BEGIN-YEAR     =1987
END-MONTH      =7
END-DAY        =31
END-YEAR       =1987
..
```

There is an individual command for each run period. Moreover, run periods now refer only to the weather file simulation periods; they are not used to specify the day or period of a design day run.

Design days are now simulated for one day only. The default days are December 21 for the winter design day and June 21 for the summer design day, but these can also be specified in the design day command.

There has been an addition to the week schedule command that allows the user to specify special day schedules to be used during the summer and winter design day simulations. Previously a week schedule had 8 "days of the week" (7 days of the week plus holiday). Two more have been added: CDD (cooling design day) and HDD (heating design day). This gives the user the opportunity of, for instance, scheduling the lights to be 100% on for 24 hours for a cooling design day simulation.

## BUILDING-LOCATION

The BUILDING-LOCATION command and its keywords have been replaced by two new commands: BUILD-PARAMETERS, containing those BUILDING-LOCATION keywords that are building specific; and SITE-PARAMETERS, containing those BUILDING-LOCATION keywords that are site specific.

### New Commands

The following table lists all of the commands in DOE-2.2. New commands are indicated by an asterisk.

#### DOE-2.2 Command Table

COMMAND NAME	ABREV	NUMB KEYS	MAX DEF
1 SCHEDULE	SCH	5	100
2 WEEK-SCHEDULE	W-SCH	1	200
3 DAY-SCHEDULE	D-SCH	11	300
* 4 SITE-PARAMETERS	S-P	16	1
5 BUILDING-SHADE	B-S	18	64
6 CONSTRUCTION	CONS	7	64
7 GLASS-TYPE	G-T	20	32
8 SPACE	S	126	128
9 SPACE-CONDITIONS	S-C	95	50
10 EXTERIOR-WALL	E-W	38	300
11 ROOF		0	-10
12 WINDOW	WI	62	200
13 INTERIOR-WALL	I-W	21	512
14 UNDERGROUND-WALL	U-W	19	64
15 UNDERGROUND-FLOO	U-F	0	-14
16 SET-DEFAULT	SET	0	100
17 DESIGN-DAY	D-D	17	3
18 LOADS-REPORT	L-R	5	1
19 LAYERS	LA	5	64
20 MATERIAL	MAT	5	128
21 REPORT-BLOCK	R-B	2	64
22 HOURLY-REPORT	H-R	8	16
23 TITLE		5	1
24 RUN-PERIOD		6	15
25 DIAGNOSTIC	LIST	0	1000
26 ABORT		0	1000
27 END		0	2
28 PARAMETER	DEFINE	0	50
29 RESET-SCHEDULE	R-SCH	0	-1
30 (not used)			
31 HELP	H	0	100
32 DEBUG	D	0	100
33 DOOR		34	64
34 WEIGHTING-FACTOR	W-F	1	128
35 TROMBE-WALL-NV	T-W-NV	0	-10
36 TROMBE-WALL-V	T-W-V	0	-10
37 WALL-PARAMETERS	W-P	13	4
38 FIXED-SHADE	F-S	18	33
* 39 HOLIDAYS	HOL	3	2
* 40 POLYGON	POLY	12	100
* 41 FLOOR	F	7	128
* 42 BUILD-PARAMETERS	B-P	10	1
43 SCHEDULE-PD		0	-1
44 WEEK-SCHEDULE-PD		0	-2
45 DAY-SCHEDULE-PD		0	-3
46 RUN-PERIOD-PD		0	-24
* 47 GLASS-TYPE-CODE	G-T-C	30	64
48 SYSTEM	SYST	374	100
49 SYSTEM-CONTROL	S-C	32	50
50 SYSTEM-AIR	S-A	28	50
51 SYSTEM-FANS	S-FANS	43	50
52 SYSTEM-TERMINAL	S-T	19	50
53 SYSTEM-FLUID	S-FLU	35	50
54 SYSTEM-EQUIPMENT	S-EQ	150	50
55 ZONE	Z	144	128
56 ZONE-AIR	Z-A	38	50
57 ZONE-CONTROL	Z-C	7	50
58 ZONE-FANS	Z-F	6	50
59 SYSTEMS-REPORT	S-R	5	1
60 DAY-RESET-SCH	D-R-SCH	0	-3
61 CURVE-FIT	C-F	25	200
62 SUBR-FUNCTIONS		108	1
* 63 PUMP		20	100
* 64 CIRCULATION-LOOP	LOOP	71	100
* 65 CHILLER		65	30
* 66 BOILER		28	30
* 67 DW-HEATER		26	30
* 68 HEAT-REJECTION		42	30
69 (not used)			
* 70 ELEC-GENERATOR		37	30
* 71 THERMAL-STORAGE		28	30
72 HEAT-EXCHANGER		29	10
* 73 EQUIP-CTRL		30	30
74 LOAD-MANAGEMENT		23	1
75 ELEC-METER		8	15
76 FUEL-METER		10	15
* 77 STEAM-METER		9	15
* 78 CHW-METER		9	15
* 79 MASTER-METERS		21	1
* 80 MATERIALS-COST		10	100

81	PLANT-REPORT	P-R	5	1
* 82	GROUND-LOOP-HX	G-L-HX	26	1
* 83	LUMINAIRE-TYPE		13	64
* 84	LIGHTING-SYSTEM		12	64
* 85	LAMP-TYPE		8	64
86	COMPONENT-COST	C-C	10	100
87	BASELINE		12	1
88	ECONOMICS-REPORT	E-R	5	1
89	UTILITY-RATE	U-R	39	30
90	BLOCK-CHARGE	B-C	25	200
91	RATCHET		6	100
* 92	WINDOW-LAYER	WL	41	32

## LOADS Changes

### Geometry

Exterior and interior walls can now be described as polygons. Previously they were required to be rectangles. Polygons can have 3 to 12 sides. Shading by building shades on polygonal walls is properly accounted for. Windows and building shades, however, must still be entered as rectangles. In DOE-2.2 spaces and walls, can “inherit” geometry from their parents by use of LOCATION keywords; default X, Y, Z, AZ, and TILT values are calculated based upon parent geometry and LOCATION values. Windows also have more “intelligent” default X and Y values to center them on their parent wall.

### Window Layers

A new command, WINDOW-LAYER, and a new WINDOW keyword, STRUCTURE, allow windows to be built up from glass, gap and blind layers. From the user-specified properties of each layer, the program calculates the overall solar, optical and thermal properties of the window for use in calculating conduction, solar gain and daylighting. This window layer feature was added to allow window blinds to be simulated. It supplements the previous shading-coefficient and window library methods of specifying windows.

### Window Blinds

DOE-2.2 calculates the conduction, solar gain and daylighting of windows with interior, exterior or between-pane blinds. Previously, blinds were (poorly) modeled as a constant multiplier on window U-value and shading coefficient that did not account for the angular dependence of blind transmission. The new blind model accounts for the dependence of conduction, solar gain and visible transmittance on slat properties (angle, reflectance, width, spacing) and on inter-reflectance between blind and glass layers.

### Lighting Systems

The new LIGHTING-SYSTEM command allows overhead electric lighting systems to be specified in terms of number of luminaires, luminaire type, lamp type and ballast type. From this information, and the associated lighting schedules, the program calculates the connected power and the average illuminance from electric lighting. Luminaires and lamps may be defined by the user or chosen from a library. If the design illuminance target is specified the program will calculate the number of luminaires required to provide that illuminance level.

### Floor

A new FLOOR command allows spaces to be grouped floor by floor. Although this does not effect the thermal calculation, it allows floor-by-floor visual display of a building.

### Daylighting

Calculation of interior daylight illuminance for windows with blinds was added (see above). Improvements were made to the calculation of exterior direct and diffuse illuminance from partly cloudy skies. The calculation of clear sky luminous efficacy now uses hourly values of atmospheric moisture (calculated from surface dewpoint temperature) rather than monthly averages.

### HVAC Changes

JJH has developed a new HVAC program for DOE-2.2 that replaces the SYSTEMS and PLANT programs of DOE-2.1. Some of the features found in DOE-2.2 were first developed and released in the JJH proprietary versions of DOE-2.1E known as DOE-2.1E versions 100 and higher (at this writing the current version is 117). The enhancements in DOE-2.1E version 100 included improved calculation of duct and piping losses, hot and chilled water reset, primary and secondary hot and chilled water loops and pumps, exhaust/relief fan scheduling, improved heat recovery for heating/cooling, residential hydronic heating, cooling towers with heat exchangers, dual-fan dual-duct VAV system, day/night reset schedules, ground source heat pumps, enhanced supermarket refrigeration models, and dual speed residential evaporative coolers. For DOE-2.2 JJH developed new simulation models for all primary equipment and merged these new models along with the 2.1E-100 SYSTEMS program into a single new HVAC program.

### Circulation Loops

Much of the effort to enhancing the HVAC modeling has been directed toward improving the connectivity between the loads incurred by the secondary HVAC systems (airhandler coils, reheat coils, etc.), and the primary HVAC equipment (boilers, chillers, etc.) For this purpose, the concept of circulation LOOPS has been implemented.

The concept of thermal loops is very similar to the concept of electric and fuel METERS which was first implemented in version 2.1E by JJH. Each electric and fuel end-use can be assigned to various meters. On an hourly basis, the METERS aggregate the energy consumption of the various end-uses assigned to them, and pass the loads onto a utility or other device (such as a generator) which then meet the demand.

A LOOP takes this same concept and applies it to end-uses that are supplied by circulating a fluid in a piping loop. Briefly, a circulation loop allows a thermal load, such as a reheat coil, to be connected to a thermal supply, such as a boiler. Different reheat coils may be connected to the same or different loops, and each loop may serve an entire system, multiple systems, or only a portion of a single system. Since each loop is connected to specific coils, different coils in the same system may be on different loops, and the connections are as flexible as is possible. For example, the central heating coil of a single-zone reheat system (SZRH) may be on one loop, the reheat coils on another loop, and the baseboards on yet another loop. Moreover, not all the reheat coils need be on the same loop; they can be assigned to different loops on a zone by zone basis. The only restriction to connecting a load to a LOOP is that the load and LOOP must be of compatible types. Using the previous example, a reheat coil may be connected to any of the hot water loops, but may not be connected to a chilled water loop. The same is true on the supply side. A boiler may be connected to a hot water loop, but not to a chilled water loop. Also, each demander or supplier may be connected to only one loop. A coil cannot draw heat from more than one loop, nor can a boiler supply heat to more than one loop (but see the discussion of primary/secondary loops).

PowerDOE incorporates a variety of different loop types. They are:

- Chilled water (CHW) - a chilled water loop supplies chilled water to cooling coils. The cooling coils may be in either central cooling equipment, such as a VAV system, or in zonal equipment,

- such as a fan-coil. In addition, a chilled water loop may be assigned to handle a process cooling load, such as a manufacturing load or a computer room unit. Chilled water loops pass their load onto one or more chillers, or to a chilled water utility
- Hot water (HW) - a hot water loop supplies hot water to heating coils. The coil types include preheat, central heating, reheat, baseboards, supplemental heat for air-to-air heat pumps, and radiant floor panel systems. Hot water loops pass their load onto one or more boilers, or to a hot water/steam utility.
  - Two-pipe (PIPE-2) - a 2-pipe loop supplies both chilled water and hot water to coils, but never during the same hour. The coils served may be any or all of the coils listed for chilled water and hot water loops. When the loop is in the heating mode, any cooling loads which may co-exist will not be met, and the temperature of the zones demanding cooling will float accordingly. The same is true for heating loads once the loop has switched over to cooling. The loop may change over from heating to cooling on the basis of an indoor or outdoor temperature, or according to a schedule.
  - Condenser water (CW) - this loop accepts the heat rejection loads of chillers, packaged direct expansion (DX) HVAC systems with water-cooled condensers, water-side economizers, and electrical generators. The loop rejects the condenser heat to one or more cooling towers.
  - Water-loop heat pump (WLHP) - a WLHP loop is primarily intended to serve water-loop heat-pump systems (system type HP). Individual WLHP units operate according to their zone thermostats, and reject heat to or take heat from the loop to which they are assigned. Depending on the relative number of units operating in the heating or cooling mode, the loop will be thermally unbalanced, and the loop temperature will either rise or fall. A boiler(s) and cooling tower(s) operate to keep the loop within the specified limits. The loop assignment may be either by system, or zone by zone.  
In addition to WLHP units, any cooling unit with a water cooled condenser may be assigned to this loop. For example, a DX cooling unit serving a computer room can reject its heat to a WLHP loop so that the computer room heat can be recovered by a WLHP unit. Chillers may also be assigned to this loop.
  - Domestic hot water (DHW) - a domestic hot water loop supplies potable heated water to kitchens, bathrooms, etc. No coils can be assigned to this type of loop, however process loads defined in the SPACE command can.

Each loop can be constant-flow or variable flow, and constant-temperature or variable-temperature. In addition, some of the loads attached to a loop may be constant-flow, while others may be variable flow. Loop temperatures may be either fixed, scheduled, reset on outside air or zone air temperature, or reset according to load.

Each loop may have one or more pumps. In variable-flow loops, the pump(s) can modulate their capacity by riding the pump curve, staging, or through 2-speed or variable speed operation. In addition, the pump's head setpoint can be fixed or vary with load, and the differential head pressure sensor can be located at various places on the loop.

The pressure loss, or pumping head, of a loop is not specified directly. Instead, the head is defined for each component in the loop, such as coils, piping, and chillers. This is so that PowerDOE can properly calculate the head as the flow varies in different parts of the loop. In addition, a static head can be specified for components which are at atmospheric pressure, such as a chilled-water storage tank, and that connect to a



loop which is pressurized.

A loop may be activated in either a passive or active fashion. In the passive mode, the loop will run whenever there is non-zero coil load. Alternatively, the loop may operate in a standby mode where it is active whenever there is an HVAC system attached to it that is running with heating/cooling schedules activated. Finally, it may operate in a scheduled mode where the heating/cooling modes of associated air handling systems are locked out when the loop is scheduled off.

Each loop can be modeled with or without thermal losses taken into account. Thermal losses may be to a conditioned zone, to the outdoors, to a tunnel, or underground. Some loops may be indoors and others outdoors, and one or more indoor indoor loops may be in the same or different zones. On an hourly basis, the thermal losses from each loop will vary according to the loop temperature (both supply and return), the temperature of the loop's environment, and the loop flowrate.

Heat may be recovered from a waste heat source to a loop. For example, the waste heat from a chiller may be attached to a hot water loop, and heat will be recovered whenever the return temperature of the loop is less than the maximum allowable condensing temperature of the chiller. In a similar fashion, heat may be recovered from the jacket of an engine-generator by attaching the jacket to a loop.

A single loop can directly deliver energy from the central plant equipment to the end-uses, or two or more loops can be arranged in a primary/secondary fashion, where a primary loop serves one or more secondary loops. A primary loop may be constant-flow while one or more of its secondaries is variable-flow, and vice versa. In addition to primary/secondary loops, central plant equipment (boilers, chillers, etc.) can have run-around loops dedicated to individual pieces of equipment, and connecting that equipment to the primary loop.

- Primary loops - a primary loop is the most basic loop, and the only mandatory component of a loop system. A primary loop can serve the demands of zero or more coils and zero or more secondary loops. It may also have zonal process loads attached, as well as a process load not specific to any zone (such as a manufacturing load). To meet these loads, the primary loop may have zero or more pieces of central plant equipment attached, or be attached to the appropriate utility energy source.  
A primary loop always has a pump, and always has a temperature control setpoint.
- Secondary loops - a secondary loop is identical to a primary loop, except that it is supplied by a primary loop rather than central plant equipment. A secondary loop may have zero or more coils demands attached, as well as the process loads described for the primary loops. It is attached to a primary loop which handles all of the secondary loop loads. A secondary loop may not be attached to another secondary loop nor can it be attached directly to any central plant equipment  
A secondary loop may or may not have its own circulation pump(s). When a secondary pump exists, the secondary loop may have its own operational schedule and temperature setpoint(s), subject to the availability and temperature of the energy in the primary loop.  
When a secondary pump does not exist, then the secondary loop operates in a purely passive fashion: it passes its load, temperature, flow, and head requirements onto the primary loop. This pump-less secondary loop is in actuality an extension of the primary loop; its main value is in allowing different legs of a primary loop to be in different zones so that PowerDOE can more accurately model the thermal losses. In addition, the coil and piping head losses can be assigned more accurately.
- Run-around loops - a run-around loop is dedicated to an individual piece of central plant equipment. It is active only when its associated equipment is active. It does not have its own

temperature control; instead it controls to the temperature setpoint of the primary loop. A run-around loop is assumed to be small in length, and does not have any capabilities for modeling thermal losses.

A run-around loop can have its own pump and can be constant-flow or variable-flow, independent of the primary loop flow. If the run-around loop does not have its own pump, then the head loss of the equipment is passed onto the primary loop.

Some types of plant equipment can have more than one run-around loop and pump. For example, an absorption chiller can have 4 run-around pumps: one for the evaporator, one for the hot water supply, one for the condenser, and one for heat recovery.

PowerDOE can simulate any number of primary and/or secondary loops, subject only to the available storage. Some of the primary loops may have secondary loops, while other primary loops may not have any secondary loops. Of course, by definition, one or more secondary loops cannot exist without an attached primary loop. The number of run-around loops is simply a function of the number and type of boilers, chillers, etc. that exist.

The use of loops has caused four of the previously existing system types to become consolidated into two new system types. The 2-pipe and 4-pipe fan coil systems (TPFC and FPFC) are now simply fan coil systems (FC). The 2-pipe and 4-pipe induction units (TPIU and FPIU) are now induction units (IU). To simulate a 2-pipe system, simply connect the fan coils to a 2-pipe loop. A 4-pipe system is simulated by connecting the hot and chilled-water coils to hot and chilled-water loops respectively. As previously described, coils in different zones may be connected to different loops.

### **PUMP command**

The new PUMP command defines all of the operating parameters of a pump. The pump may be attached to either a primary or secondary loop, or be the run-around pump on a unit of primary equipment, such as a chiller.

### **Constant vs. Variable Flow**

The primary and secondary loops may be either constant flow (3-way valves), or variable flow (2-way valves). Flow control may also be mixed. For example, some secondary system loops may be variable flow, while other system loops served by the same primary loop may be constant flow. In turn, the primary loop serving these systems may be either variable flow or constant flow.

DOE-2 can simulate single-speed, 2-speed, and variable-speed pumps, both primary and secondary. Primary pump(s) may be of one type, and secondary pump(s) of another type. In addition, the type may be different for each secondary system.

When simulating variable-speed pumps, two control modes are available:

1. Constant head pressure set-point: This is the most common strategy used in buildings today. In this mode, the controls modulate the speed of the pump to maintain a constant differential pressure between the supply and the return. DOE-2 assumes that this differential pressure is measured toward the end of the piping run, and corresponds to the head required to force the design flow through a coil and valve.
2. Variable head pressure set-point: This strategy is less common, but can save additional pump energy when coupled with a direct digital control system. As before, the pump speed is

controlled on the basis of the pressure differential between the supply and the return. However, the differential pressure set-point is not constant. Instead, the DDC system monitors the positions of the coil valves, and resets the differential pressure set-point so that one of the coil valves is fully open. This minimizes the energy lost through valve throttling, and allows the pump performance to more closely approximate the ideal pump laws. (The ideal pump laws state that the horsepower varies as the cube of the flow. This is *never* true when a pump is controlled to a constant differential pressure set-point.)

### CHILLER command

This is a new command which defines all of the operating parameters of a chiller. Most keywords are the same as the previous keywords that were scattered across the PLANT-EQUIPMENT, PART-LOAD-RATIO, PLANT-PARAMETERS, and EQUIPMENT-QUAD commands, but are now combined together in one command.

In previous versions of the program, all chillers of the same type (such as open centrifugal) had identical performance characteristics; only the size could be varied from one chiller to the next. Now, the program treats each chiller as a completely separate entity from all others, and you may specify the efficiency, off-design performance characteristics, etc. for each individual chiller.

To accomplish this, a new CHILLER command replaces the old PLANT-EQUIPMENT command, and all of the performance specifications that used to be in the PART-LOAD-RATIO, PLANT-PARAMETERS, and EQUIPMENT-QUAD commands are now contained within the CHILLER command. Types of chillers include ELEC-OPEN-CENT, ELEC-OPEN-REC, ELEC-HERM-CENT, ELEC-HERM-REC, ELEC-HTREC, ABSOR-1, ABSOR-2, GAS-ABSOR, and ENGINE.

As each chiller is a completely separate entity, you no longer define the number of chillers of a given type and size; you define each chiller separately even when they are identical.

Keywords are available to define the energy consumption of the chiller. Not all keywords are used for every chiller type. For example, an electric chiller does not consume any heat or fuel, and so does not have an HIR. However, an absorption chiller may have electrical usage, such as for a spray pump, and the electrical consumption of this pump may vary with load. Consequently, the heat- and fuel-chillers use both the EIR and HIR set of keywords.

A set of keywords is used to describe how a chiller is attached to a chilled-water loop; for absorption chillers, keywords are also used to describe attachment to a hot-water or steam loop. If the chiller has a dedicated pump in a run-around loop, the pump is attached to the chiller from within the chiller command. For all chillers, the keywords are available to describe attachment to a condenser water loop. If the chiller has a dedicated condenser-water pump in a run-around loop, the pump is attached to the chiller from within the pump command.

Several keywords are also available to define any heat recovery available from a chiller. Any chiller is capable of heat recovery in a temperature range similar to the design condensing temperature. For higher temperature heat recovery, the HTREC-CHLR should be defined. For heat recovery, it is assumed that the chiller has a second condenser that attaches to a HW, WLHP, or DHW loop (often termed a double-bundle condenser). When a heating demand is present and the loop return temperature is below the MAX-RECOVER-T, then the condenser loop temperature controls are overridden so that heat is rejected at either the MAX-RECOVER-T or the loop's supply temperature setpoint, whichever is less. Any heat not recovered to the heating loop will be rejected to the condenser-water loop.

### **BOILER command**

This is a new command which defines all of the operating parameters of a boiler. Please refer to the introduction to the CHILLER command for a summary of the command changes from previous versions of the program. Available types of boilers includes HW-BOILER, HW-BOILER-W/DRAFT (fan), ELEC-HW-BOILER, STM-BOILER, STM-BOILER-W/DRAFT (fan), and ELEC-STM-BOILER.

### **DW-HEATER command**

This is a new command which defines all of the operating parameters of a domestic water heater. Normally, the heater comes with a storage tank, but you can also simulate instantaneous water heaters by setting the tank volume to a very small number. Please refer to the introduction to the CHILLER command for a summary of the command changes from previous versions of the program.

These heaters attach to a CIRCULATION-LOOP of TYPE=DHW, and provide heated water for domestic purposes such as dishwashing, showers, etc. In addition, heating coils can be attached to a domestic water loop, in which case the heater can provide space heating as well as domestic water loads. Types of DW-HEATERS available include GAS, ELEC, HEAT-PUMP.

### **HEAT-REJECTION command**

This is a new command which defines all of the operating parameters of heat-rejection devices such as cooling towers, fluid coolers, and dry coolers. A HEAT-REJECTION device may be attached to CIRCULATION-LOOPS of TYPE = CW or WLHP.

Cooling towers may be directly attached to a loop (open tower), or may include an intermediate heat exchanger. The algorithms model the performance of a tower for wetbulbs ranging from 20°F to 82°F, leaving temperatures of 40°F to 95°F, and temperature drops from 1°F to 20°F. For this range of conditions, the algorithms will predict the leaving tower temperature with an accuracy of less than 1°F for most common operating conditions, and a maximum error of 2°F for the more extreme conditions (very large or very small temperature drops, and very close approaches to the wetbulb).

Types of HEAT-REJECTION devices include OPEN-TWR, OPEN-TWR&HX, FLUID-COOLER, and DRYCOOLER. The algorithm for the open tower is similar to the algorithm in DOE-2.1E, except for the form of the performance curves. The open tower with heat exchanger, fluid cooler, and dry cooler are new.

For open cooling towers and fluid coolers, keywords are available to define the unit capacity, and how the capacity varies with load, ambient conditions, and loop temperature setpoint. Cooling towers and fluid coolers differ from other types of primary equipment in that manufacturers commonly rate their equipment in terms of how much water the unit can cool (gallons per minute), rather than the actual heat rejection capacity (Btu/hr), although the two are equivalent to each other. This program compromises between the two approaches: If you specify a capacity, it is in Btu/h. The design routine then calculates the fluid flow rate that corresponds to this capacity at your design conditions, and determines the equivalent size tower normalized to the Cooling Tower Institute (CTI) design conditions. The CTI design conditions are 95°F entering the tower, 85° leaving the tower (10°F range), when the wetbulb is 78°F (7°F approach).

The OPEN-TWR&HX component consists of an OPEN-TWR coupled to its circulation loop via a HEAT-EXCHANGER. The default tower performance curves for this component are the same as for the OPEN-TWR. However, since the heat exchanger creates a temperature differential between the loop and the tower, the tower's performance will be degraded and its energy consumption will be higher compared to an OPEN-

TWR directly coupled to a loop, when operating at the same conditions. Since the heat exchanger isolates the tower from the loop, the tower must have its own pump to circulate fluid between the tower and the heat exchanger.

Fluid coolers may operate with a dry coil during winter conditions when the spray water would be subject to freezing conditions. During these periods, the pan may be drained and the spray pump disabled. The fluid cooler will then operate with a dry coil in a manner identical to a dry cooler. Heat transfer across the coil may be substantially degraded during these times, depending on the drybulb temperature. For this reason, the outdoor temperature must be relatively cold for the cooler to deliver its design capacity.

As described previously, fluid coolers may need to operate in the winter, most commonly to reject heat from a water-loop heat-pump system. The pan can be protected from freezing by draining it and running the cooler with a dry coil, however this does not prevent the coil itself from freezing during times the loop is shut down. Freeze protection for the coils commonly consists of one of the following measures:

1. Locating the fluid cooler in an enclosed space
2. Using a glycol mixture in the loop, or
3. Restarting the loop and circulating heated fluid through the cooler whenever the ambient conditions endanger the coil.

While option #3 is the least energy efficient (particularly in cold climates), it is also the least expensive option and is commonly done. Keywords are available to define the heat loss characteristics of the coil during this mode of operation.

If a tower or fluid cooler is located outdoors, and must operate at near or below freezing temperatures, then some means must be provided to prevent the water in the pan from freezing when the unit is not operating. One method is to drain the water and store it in a remote sump located in an area not subject to freezing. The pan in a fluid cooler can be drained, the spray pump disabled, and the unit operated with a dry coil for the duration of the winter (see the section on fluid cooler dry coil operation). Another method is to provide a thermostatically-controlled pan heater. Keywords are available for these options.

A drycooler is simply an air-to-water heat exchanger with one or more integral fans. The device is located outdoors and rejects the heat of a condenser water loop. Since the unit is not evaporatively cooled, the loop temperature will always be above the ambient drybulb temperature. In hot climates, this can have a significant impact on cooling unit efficiency. Keywords are available for these options.

## HEAT RECOVERY in DOMESTIC WATER SYSTEMS

DOE-2.1E was capable of recovering heat from direct-expansion air conditioning systems to the domestic water heater. This functionality is preserved and expanded in the current program. In addition, heat can now be recovered from chillers and generators and applied to domestic water heating loads.

Heat recovery from direct-expansion air conditioning units is functionally similar to earlier versions of the program. The amount of superheat available is calculated, and reduced by the amount recovered for space heating. The remainder is available for recovery to a DW-HEATER via a heat exchanger located in the heater's storage tank. Since the program can now simulate multiple domestic water heaters, you must specify which heater is to receive the waste heat, and how much waste heat the heater can accept through keywords.

Energy for domestic water heating can also be recovered from the condensers of CHILLERS or the cooling

jacket or exhaust of ELEC-GENERATORS. Unlike DX superheat recovery, this heat does not go directly into a water heater's storage tank; instead it is recovered on the makeup/return side of a domestic hot water CIRCULATION-LOOP, and preheats the water entering the attached water heaters. Because the heat is recovered to the loop, no heat can be recovered during hours there is no loop flow.

### **MATERIALS-COST command**

This is a new command that defines the costs associated with a given primary equipment component. These costs include first costs, operating costs (other than energy), maintenance costs and intervals, etc. Components such as CIRCULATION-LOOPS, PUMPS, and CHILLERS reference this command via its mandatory U-name.

### **ELEC-METER command**

The DOE-2 program had allowed the specification of up to five electrical meter to which any electrical “end use” class could be connected; these connections were specified by using the M1, M2, M3, M4, or M5 codewords. This has been extended by the addition of the ELEC-METER command where one can define up many meters to which electrical equipment could be attached. We have added to concept of meter levels so as to allow a flexible ability to define sub-metering of usage and demand. This concept is implemented entirely within the ELEC-METER command through the use of the TYPE keyword. The ELEC-METER command is now a “TYPE” command; thus the TYPE keyword is required and must appear as the first keyword in the list for the ELEC-METER command.

Three TYPEs of ELEC-METERs can be defined: UTILITY, BUILDING, and SUB-METER. These TYPEs define three meter levels with SUB-METER being the lowest, BUILDING being the middle, and UTILITY being the highest. The intention is that all meters that are to be connected to a UTILITY-RATE should be of TYPE = UTILITY; this is not an enforced restriction, but if another type of meter is connected to a UTILITY-RATE there will most likely be double counting of energy consumption by the ECONOMICS program. Each meter level can have associated transformers which can include losses and part-load performance characteristics.

All non-UTILITY types of ELEC-METERs must be attached to a ELEC-METER of a higher level; each SUB-METER must be attached to one (and only one) BUILDING or UTILITY meter, and each BUILDING meter must be attached to one (and only one) UTILITY meter. In this manner a three level tree is constructed that contains all meters. The consumption/demand for BUILDING and SUB-METER TYPEs is summed into their parent ELEC-METER; thus reports for UTILITY and BUILDING meters contain the component consumption/demand of all lower level (child) meters.

This structure allows the description of a site (with a site substation transformer) with multiple buildings, each with its own BUILDING meter plus transformer and, possibly floor-by-floor SUB-METERs and transformer.

### **FUEL-METER command**

As with ELEC-METERs, one can define multiple FEUL-METERs and define the TYPE of fuel used. Each FUEL-METER is then connected to a UTILITY-RATE. As in DOE-2.1E, each piece of fuel consuming equipment can have its fuel meter connection independently specified.

### **STEAM-METER and CHW-METER commands**

These are new commands that define the parameters for steam and chilled-water meters. These meters attach to a loop and provide the required heating or cooling to the loop. The meter may meet all of the load (no other heating/cooling equipment attached to the loop), or be coordinated with other primary equipment to provide only part of the load. The program passes the meter consumption data onto the ECONOMICS module so that costs can be determined.

### **THERMAL-STORAGE command**

This is a new command that defines all of the operating parameters of thermal storage devices. Most of the keywords contained in this command are the same as the previous keywords that were scattered across the PLANT-EQUIPMENT, PART-LOAD-RATIO, PLANT-PARAMMETERS, and ENERGY-STORAGE commands, but are now combined together in one command.

Like other primary equipment components, you define a storage component and attach it to a loop. The rules for loop attachments are a little different for thermal storage devices, as they can be charged from and discharge to different loops:

1. A loop can be supplied by at most one storage device.
2. More than one storage device can demand from a loop.

A storage device can be charged from and discharge to either the same or different loops. When using the storage components, it is important that you understand their limitations, and how those limitations affect your analysis. The current program release incorporates *Btu-based* models of hot-water and chilled-water storage tanks that are essentially identical to the original algorithms contained in DOE-2.1E. The models are Btu-based because they assume that a unit of energy put into storage can be taken out again in an un-degraded form

### **HEAT-EXCHANGER command**

This is a new command which defines all of the operating parameters of a heat exchanger. Currently, heat exchangers are used to:

- Isolate a cooling tower from a condenser loop or water-loop heat-pump system (OPEN-TWR&HX),
- Model the performance of drycoolers (DRYCOOLER), and
- Model the performance of fluid coolers when running dry (FLUID-COOLER)

### **Pipe and Duct Losses**

Previous versions of DOE-2 had very limited capabilities for simulating duct and pipe losses. Duct losses, both air losses and conductive losses, were simulated in SYSTEMS as constant values, independent of temperature. In addition, the energy simply disappeared; it was not accounted for in any zone. Piping losses were simulated in PLANT. As with duct losses in SYSTEMS, piping losses were assumed to be constant with temperature, and simply disappeared.

All duct and piping losses are now simulated in the new HVAC program. The zone in which these losses occur is specified, and all losses are dependent on the temperature differences between the fluids and the ZONE in which the duct or piping is located.

Hot and chilled-water temperatures can now be reset as a function of load. This reset affects the piping losses, the fluid flows, and the efficiency of the chillers. Previously, any reset specified in PLANT had no effect on either the piping losses, or the fluid flows and pumping horsepower.

Numerous keywords are specific to duct and piping losses. Other related keywords, such as those that define the supply temperature of the fluid, the temperature drop of the fluid through a coil, and temperature reset functions, are discussed in later.

### Hot and Chilled-water Reset

DOE-2 can reset the temperature of the hot and/or chilled-water loops so that one coil valve is fully open (full flow). All other hot-water coil valves will modulate as required to maintain the supply air temperature set-point. Alternatively, the loop temperature may be reset on outdoor temperature. These strategies reduce the piping losses, but may increase pumping power in systems with 2-way valves. DOE-2 can now allow designers to evaluate these trade-offs.

When multiple pumps, 2-speed pumps, or variable-speed pumps are used together with 2-way valves, the program will attempt to reset the hot-water temperature so that the water flow of the most heavily loaded coil is 60% of design. This strategy allows pump savings to be achieved simultaneously with reduced piping losses.

### Exhaust Fans and Heat Recovery

Previously, all of a SYSTEMs fans (supply, return, and exhaust) were assumed to be connect via the same switching and thus the FAN-SCHEDULE controlled the operation of all fans. A keyword has been added to allow the exhaust fans to be controlled separately.

Previously, when it was desired to recover energy from the relief air to the outside air supply only heat could be recovered and no electrical energy was consumed. Now heat and cool recovery can be modeled along with electrical power required to run the recovery equipment.

### Hydronic Systems

A new hydronic heating option has been added all air-system models systems. The heating coils for a SYSTEM can now be to a domestic water heater supplied heating loop, which causes the simulation of a hot water hydronic heating system combined with the domestic hot water heating tank. The simulation assumes a water coil is located within the air handler to supply the heat into the air stream in the heating mode. The hot water is supplied by the domestic hot water heater specified in the DW-HEATER command. The cooling is supplied by the normal source for the SYSTEM.

### Dual Fan Dual Duct VAV System

The single-fan dual-duct algorithm of DOE-2.1E has been expanded to permit the modeling of dual-fan dual-duct systems as well. As part of these modifications, additional keywords have been added, some of which apply only to the dual-fan system, and others to the program in general.

In the new dual-fan system, the hot deck fan can be controlled independently of the cold deck. It can operate according to a different schedule, have a different capacity control mechanism, be night-cycled independently of the cold deck, have a blow-thru fan while the cold deck is draw-thru, etc.

Many of the new capabilities apply to all of the dual-duct systems (single-fan dual-duct, dual-fan dual-duct, multi-zone, and packaged multi-zone). Minimum flow ratios for each zone mixing box can be specified for the cold duct, the hot duct, and the box outlet. This allows most of the common control sequences to be readily simulated. Alternatively, the min-cfm-ratios can approximate damper leakage. For example, during peak cooling, the hot duct damper may be leaking air in excess of 100°F into the zone. This leakage will act to increase the cooling load, the cooling flow-rate, the cooling fan horsepower, and the chiller energy. This



effect can now be accurately investigated. In fact, the design routine takes into account the damper leakage from the opposite duct when determining the default zonal hot and cold air flow-rates.

Additional modifications apply to all applicable systems. The return fan, if specified, can now be controlled independently of the supply fan (discharge dampers, inlet vanes, etc.). The default return fan capacity can be specified as a percentage of the supply, with the balance of air assumed to be exfiltrating via building pressurization.

A relief (central exhaust) fan can be simulated in place of a return fan. The relief fan operates only as needed to relieve air drawn in through the economizer, and not exhausted through any zone level exhausts. Instead of specifying the MIN-CFM-RATIO for a VAV system, the user can now specify the MIN-CFM/SQFT. This value (for example 0.5 cfm/sq.ft. minimum) will be multiplied by the zone floor area to determine the minimum allowable airflow rate. That value is then divided by the peak cooling flow-rate to determine the MIN-CFM-RATIO. Therefore, the user may allow the program to size each VAV box, but still be assured that a minimum airflow based on square footage will always be delivered.

New and existing keywords now limit the range over which the supply air temperature can be reset when using COOL-CONTROL=WARMEST and HEAT-CONTROL=COLDEST. The existing keywords COOL-SET-T and HEAT-SET-T act as the lower limit for cooling and upper limit for heating respectively. COOL-MAX-RESET-T has been added to act as an upper limit for the cold-deck temperature, and HEAT-MIN-RESET-T is the lower limit for the hot deck temperature. Of course, these temperatures may not be maintained if the system has insufficient capacity, or if cooling/heating is scheduled off.

Previously, when using COOL-CONTROL=WARMEST or HEAT-CONTROL=COLDEST, the program always reset the supply-air temperature first, and the airflow second. Now the user can specify the RESET-PRIORITY so that different reset schemes can be investigated.

One of the new keywords, HMIN-CFM-RATIO was developed for the dual-duct systems, but has meaning for single-duct VAV systems as well. When THERMOSTAT-TYPE = PROPORTIONAL, the VAV box will normally be at the MIN-CFM-RATIO during heating. Specifying HMIN-CFM-RATIO to a value greater than MIN-CFM-RATIO will cause the box to jump to the flow-rate corresponding to the HMIN-CFM-RATIO whenever the zone requires heating, rather than staying at the MIN-CFM-RATIO. (During cooling or dead-band modes, the box will modulate down to the MIN-CFM-RATIO as before.) This simulates the action that some DDC VAV controllers initiate in order to minimize problems with space temperature stratification during heating. (The Barber-Colman Network 8000 MicroFlo controller is an example of a VAV box controller which behaves in this fashion.)

As part of these changes, the algorithm which sets the supply air temperature(s) at the beginning of the hour was modified to better estimate what the actual supply temperatures and airflow rates can be. (This was done in anticipation of a future merge of the systems and plant programs.) As a result, the hourly hot and cold deck temperatures may not be exactly the same as before, and the user can expect to see small changes in the annual energy results for most system types. This effect may be most noticeable when resetting supply air temperatures using COOL-CONTROL = WARMEST and HEAT-CONTROL = COLDEST.

The dual-duct algorithms can simulate a wide variety of control sequences at the mixing box, both constant-volume and variable-volume. DOE-2 can simulate controllers on both the hot and cold ducts, as well as the box outlet. Normally, a maximum of two controllers are used per mixing box. The controller(s) are usually on the hot and cold ducts, while the controller sensors may be either in the duct inlets or the outlet of the box.

### Day and Night varying RESET-SCHEDULEs

The capability to define outside air temperature based reset control has been enhanced to allow the description of two reset relationships per day rather than a single relationship. This enhancement is designed to allow the description of “day” and “night” reset relationships so that the occupied and unoccupied hours resets can be different. This new feature is implemented in the DAY-RESET-SCH command. This command can only be referenced in schedules that are defined as RESET-SCHEDULEs.

### Residential Two-Speed Evaporative Coolers

The capability to model residential evaporative coolers with two speed fans as well as combined DX and evaporative cooling has been added to the SYSTEMS program SYSTEM-TYPE = RESYS. In earlier versions the RESYS evaporative cooler simulation did not work properly.

### GROUND-LOOP-HX command

The capability to define and simulate ground source heat pump (GSHP) systems has been added. Ground coupled systems that incorporate either fields of vertical wells or trenches containing horizontal loops (straight runs or “slinky” spirals) can be modeled. The ground models, like the balance of DOE-2, use an hourly time-step simulation to estimate the ground loop performance. The heat pumps that provide the heating and cooling to the spaces are simulated as with the conventional water loop heat pump (WLHP) system.

The new models include the ability to simulate new as well as existing systems. The number of years the systems has been installed, prior to the simulation being performed, is defined to allow more accurate ground field initialization. In this way the effects of ground temperature drift can be estimated. The initialization of the ground is done using a user supplied (or calculated) heating and cooling design day 24-hour profile. These profiles are used, along with specified heating and cooling peak day numbers (Julian day number) to create one or more years of “history” during the initialization of the ground coupled system. If these 24-hour profiles are not specified in the building description explicitly the program will create these profiles using the results of the DESIGN-DAY RUN-PERIODs.

The ability to specify a field multiplier is also included; this allows the definition of very large symmetric systems (where interactions of portions of the field are minimal compared to the individual system components).

### Overview of the Simulation of Vertical Wells

The routines VWELL and VWELLG provide the capability for the simulation of single, or multiple parallel, vertical well(s) used with a ground-source heat pump. A U-Tube configuration is assumed. Transient effects in the well and above-ground loop are neglected. The well is assumed to be in good contact with a soil that has uniform properties, and is at a constant far-field temperature.

The main function of the VWELL and VWELLG routines is to determine the temperature of the water loop, based on the net heat transfer to the loop during the hour. Because of the overall structure of DOE-2, and the possibility of multiple heat pumps on the same loop, some of which may in a cooling mode while others are in a heating mode, the ground-loop analysis and the heat pump performance calculations must be carried out separately.

## Overview of DOE-2.2

The Kavanaugh model is used to represent the equivalent pipe resistance for the U-tube, including thermal shorting between the legs of the U-tube.

Nineteen (19) well field configurations are represented and are user selectable:

- |                                     |                                       |
|-------------------------------------|---------------------------------------|
| 1) single well,                     | 11) 9 wells in a square,              |
| 2) 2 wells in a line,               | 12) 15 wells in a rectangle (5 x 3),  |
| 3) 3 wells in a line,               | 13) 16 wells in a square,             |
| 4) 4 wells in a line,               | 14) 12 wells in a rectangle (4 x 3),  |
| 5) 6 wells in a line,               | 15) 12 wells in a rectangle (6 x 2),  |
| 6) 8 wells in a line,               | 16) 16 wells in a rectangle (8 x 2),  |
| 7) 10 wells in a line,              | 17) 20 wells in a rectangle (10 x 2), |
| 8) 3 wells in a triangle,           | 18) 18 wells in a rectangle (6 x 3),  |
| 9) 4 wells in a square,             | 19) 32 wells in a rectangle (8 x 4).  |
| 10) 6 wells in a rectangle (3 x 2), |                                       |

### Overview of the Simulation of Horizontal Loops

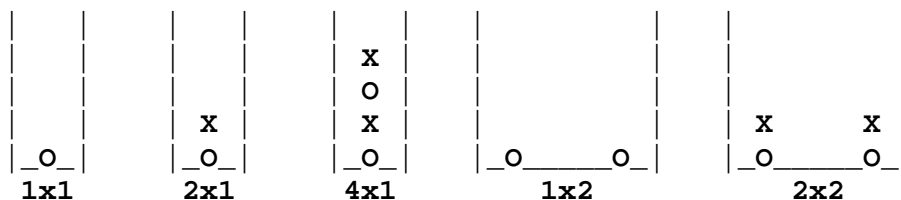
The new routines HLOOP, HSOIL, and VWELLG allow the simulation of a horizontal loop ground heat exchange for use with a ground-source heat pump. Straight tubes are assumed. Transient effects in the loop are neglected. The loop is assumed to be in good contact with a soil that has uniform properties. In the absence of the loop, the soil temperature satisfies:  $T_g = T_m - A_s(D) \cos(ARG)$  where  $A_s$  = function (depth and soil properties) and  $ARG$  = function (time, depth, and soil properties). Using the superposition principle, the actual soil temperature is the undisturbed temperature and a disturbance due to heat gain or loss. The time-dependent heat term is treated by considering the heat exchange as a series heat pulses.

As with the vertical well simulation, water-source heat pump is assumed to be part of a water-loop (California) heat pump system. In this arrangement, multiple heat pumps are connected by a common heat transfer loop which acts as a source or sink to each heat pump. The heat transfer loop is part of a horizontal loop ground coupling. The main function of the HLOOP and HSOIL routines is to determine the temperature of the water loop, based on the net heat transfer to the loop during the hour.

Six (6) horizontal pipe configurations are represented by a user selected configuration number:

- 0) horizontal U-tube,
- 1) single pipe (1x1),
- 2) two pipes in series-flow, one over the other (2x1),
- 3) four pipes, in sets of two parallel two-pipe arrangements (4x1),
- 4) two pipes in parallel flow at the same depth (1x2),
- 5) four pipes with two parallel two-pipe arrangements, each parallel loop at same depth (2x2).

A simple illustration is shown below:



Multiple, parallel, trenches can be specified. This is done by specifying the number of trenches and the average separation between them.

Slinky coils are also represented. The user selected configuration number for these configurations are:

- 6) horizontal coils, laid on the bottom of the trench, and

7) vertical coils, laid against the side of the trench.

Slinky coils are modeled as equivalent U-bend heat exchangers using an approximate model developed by MD Smith, Oklahoma State University and generalized here to more common slinky coil designs.

First, the number of turns of pipe (nTurns) actual length of pipe (PL) used in the slinky arrangement is calculated:

$$\begin{aligned} \text{nTurns} &= 12.0 * (\text{TRENCH-LENGTH-SLINKY-DIAMETER}) / \text{SLINKY-PITCH} \\ \text{PL} &= \text{nTurns} * 3.1415927 * \text{SLINKY-DIAMETER} + 2.0 * \text{TRENCH-LENGTH} \\ &\quad + (3.1415927 / 2.0 - 1.0) * \text{SLINKY-DIAMETER} \end{aligned}$$

Next, the fractional coverage of face area (f\_area) by the coil is calculated:

$$\begin{aligned} \text{f\_area} &= 3.1415927 * \text{PIPE-OUTSIDE-DIA} / 12.0 \\ &\quad * \text{PL} / (2.0 * \text{TRENCH-LENGTH} * \text{SLINKY-DIAMETER}) \end{aligned}$$

Lastly, a polynomial as a function of coverage ratio is used to determine an equivalent length of U-tube pipe (EPL) (based on generalizing data from MD Smith) and the adjusted trench length (ATL) is calculated:

$$\begin{aligned} \text{EPL} &= \text{PL} / (0.98 + 0.24 * \text{f\_area} + 1.475 * \text{f\_area} ** 2) \\ \text{ATL} &= \text{EPL} / 2.0 \end{aligned}$$

### HVAC Primary Equipment Controls

The DOE-2 program had several means by which the primary plant equipment (boilers, chillers, etc.) could be controlled:

1. The default algorithms selected a mix of equipment (such as boilers) that best satisfied a load (such as heating). The best match was determined using the OPERATING-RATIO of the equipment.  
The program could also attempt to optimize the overall operation of a plant. For example, if a plant contained an electric generator together with electric and absorption chillers, the program would attempt to select the mix of chillers that best utilized any recoverable heat from the generator.
2. Alternatively, the user could specify the performance of the equipment using the LOAD-ASSIGNMENT and LOAD-MANAGEMENT commands. The LOAD-ASSIGNMENT command allowed the user to specify the mix of equipment for particular load ranges. The LOAD-MANAGEMENT command allowed the user to vary the LOAD-ASSIGNMENTS used based on either a schedule, or an overall mix of heating, cooling, and electrical loads.
- 3.

The PowerDOE algorithms are similar in some ways, and different in others:

1. Similar to before, there is a default load allocation routine. For each loop, this routine selects the mix of attached primary equipment that most closely matches the load. The selection algorithm attempts to fully load the equipment; the optimum OPERATING-RATIO keyword has been eliminated as it never accounted for the differences in efficiency that the equipment units could have. (For example, a high efficiency chiller at full load could be much more efficient than a less efficient equipment unit operating at its optimum OPERATING-RATIO.) Unlike before, the program will not attempt to optimize a mix of electric and absorption chillers based on recoverable heat available from cogeneration equipment.

2. The LOAD-ASSIGNMENT command has been replaced with the EQUIP-CTRL command. The two commands are functionally similar. The major difference is that the EQUIP-CTRL command must be assigned to a specific circulation loop, and will accept equipment entries that are only for that loop.
3. The LOAD-MANAGEMENT command still exists but is functionally more powerful than before. As before, this command contains a schedule that allows EQUIP-CTRL commands to be switched on a time of day or time of year basis.

### **EQUIP-CTRL command**

The EQUIP-CTRL command allows you to override the default routines that allocate a CIRCULATION-LOOP's heating or cooling load to the attached primary heating or cooling equipment. If an EQUIP-CTRL command is not referenced by a CIRCULATION-LOOP, then the program will automatically select the mix of equipment attached to the loop with a combined capacity most closely matching the load, but preventing an overload condition.

If you wish to use the same EQUIP-CTRL sequence all year for a given CIRCULATION-LOOP, then you can define a single EQUIP-CTRL sequence for that loop, and reference it directly from the CIRCULATION-LOOP command. If, however, you wish to change control strategies on a time of use basis, or want to implement an electrical peak shaving strategy for your building, then you must define multiple EQUIP-CTRL sequences for a given loop, and use the LOAD-MANAGEMENT command to select the appropriate strategy on an hourly basis.

An EQUIP-CTRL command can only apply (be attached) to one CIRCULATION-LOOP. This is a direct consequence of the fact that any given piece of primary equipment can be attached to only one CIRCULATION-LOOP.

### **LOAD-MANAGEMENT command**

The LOAD-MANAGEMENT command is used to allow dynamic linking of EQUIP-CTRL commands to CIRCULATION-LOOPS. Since more than one EQUIP-CTRL sequence may be defined for any given loop, the LOAD-MANAGEMENT command is used to specify which EQUIP-CTRL will be applied in any given hour.

The LOAD-MANAGEMENT command operates at a level above the CIRCULATION-LOOPS and their associated EQUIP-CTRL commands. For example, based on a building electrical load, the LOAD-MANAGEMENT command can select a group of EQUIP-CTRL sequences and use them to control the primary equipment attached to their respective loops. In this fashion, cooling loads can be shifted from electric chillers to absorption chillers or to thermal storage tanks in order to keep the building peak below a target value.

### **New Features in Refrigerated Casework**

A number of new features have been added to DOE-2.2 to allow the more accurate simulation of supermarket refrigeration systems.

The features added include:

- the ability to model anti-sweat heater that are either controlled by the space humidity level or operate at a constant output;

## **Overview of DOE-2.2**

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- the ability to model two stage heat recovery - superheat only and use of hold back valves;
- the ability to model air and evaporative condensers with various types of fan and temperature controls;
- other miscellaneous items as described below;
- ability to specify loads from walk-in boxes and preparation rooms.