MODELING OFFICE BUILDINGS WITH DOE-2

Tim Steele
Bonneville Power Administration
Portland, OR

ABSTRACT

DOE-2 is arguably the most complex and comprehensive building energy simulation program available. However, not even DOE-2 addresses ali situations encou ntered in commercial office buildings. Most buildings contain one or more of the following situations:

o Heated and cooled by systems not available in simulation program.
o Number of HVAC systems and/or zones exceeds limits of simulation program. a Multiple chillers of different size and efficiencies. DOE-2 allows multiple chillers, but does not allow assignment of chillers to specific systems.
a New and irmovatíve HVAC control systems. Automatic room temperature and lighting controls found in new control system specifications exceed the limits of DOE-2 and require additional modeling assumptions.

This paper is an examination of these typically encountered problems and how they were addressed thru modeling studies performed over the last three years. Case studies are used to emphasize the problems. Modeling approaches used are presented and explained.

Note that most of these problems will be solved by the PowerDOE vcrsion of DOE-2, scheduled to be released in late 1995 (reference 1).

INTRODUCTION

Modeling office building energy use is more complicated than simply inputting building parameters into an energy simulation program. Commercial office buildings vary widely in size, shape, type and condition of mechanical and electrical systems, and operating practices. This variability is both the reason why it is necessary to perform energy modeling and the reason why "comprehensive" energy simulation models are not absolutely comprehensive.

If all commercial office buildings were identical, or almost identical, then only one energy model would be necessary. This model could be run with different weather conditions and with a limited set of input parameters for all buildings. Because this is not the case a general energy simulation model is required to account for all the different building configurations.

One of the most popular building energy simulation programs over the past several years was DOE-2.1D. In the states of Oregon and Washington DOE-2.1D was used almost exclusively by electric utilities in their DSM activities. Although DOE-2.1D is used as the example building energy simulation program, similar situations are found in all hourly simulation programs.

DOE-2.1D is an hourly energy simulation program with extensive capabilities for modeling commercial building energy use and cost. Even with these capabilities almost all large office buildings will have features or characteristics that can not be directly modeled on DOE-2 (or other building energy simulation programs).

This paper is a discussion of some of the more common and important situations encountered when modeling large office buildings with DOE-2.1D during the past three years. Approaches that were used are discussed and their relative inaccuracies considered. Note that alternatives to these approaches could have been undertaken with probably similar results. Reference 2 presents a detailed discussion of similar situations along with numerous other building energy simulation issues.

Most of the problems discussed in this paper will be solved by the PowerDOE version of DOE-2, scheduled to be released in late 1995.

The capability of DOE-2 to allow modeling of User Input Functions is not considered an option. The use of User Input Functions requires time and testing which are usually not options for most production-type energy simulations.

DISCUSSION

Simulation of commercial building energy use can be compared to many engineering problems. Similar to engineering problems, no one solution will work in all cases, and engineering judgment is needed to find problem solutions. The ability to input a building description and conduct an energy simulation is not adequate in most cases. The modeler also needs to determine what are the appropriate assumptions given energy simulation program, time, and money constraints.

All energy simulation programs have limitations and input constraints. Most large office buildings exceed these limitations in one way or another. This section is split into four commonly encountered problems associated with hourly building energy simulation programs. Examples of solutions to these problems used in energy studies are presented. The four problem areas discussed are:

1. Heated and cooled by systems not available in energy simulation.
2. Number of HVAC systems and/or zones exceeds limits of program.
3. Multiple chillers of different size and efficiencies. DOE-2 allows multiple chillers, but does not allow assignment of chillers to specific loads or systems.
4. New and innovative HVAC control systems. Automatic room temperature and lighting controls found in new control system specifications exceed the limits of energy simulations and require gross assumptions by the modeler.

1. Heated and cooled by systems not available in energy simulation.

For DOE-2.1D, system types which were found in practice but not found in DOE-2.1D, include Dual Duct/Dual Fan VAV and Triple-Deck Multizone. (See reference 3 or reference 5 for a complete listing of HVAC system types available with DOE-2.1D.)

A. The Dual Duct/Dual Fan VAV system used the Heating fan to provide perimeter heat only through a central heating hot water coil. (The actual building had three such fan systems located in the penthouse). This system was simulated as the DOE-2 VAV system. Two potentially critical estimating problems are expected from this approach: Fan power and mild weather heating/cooling.

The heating fan power and cfm were assumed to be accounted for in the calculations of zone heating and cooling air demands. Measured fan power (overall or heating or cooling) versus delivered air was not available. Interior zones were modeled as cooling only, perimeter zones were modeled as being conditioned with reheat boxes. Since the system(s) would never operate as heating only, the minimum power would always be greater than the heating fan power. Just what the actual minimum fan power should be is not known.

During periods of economy cooling and perimeter heating, the modeled system should overestimate heating requirements and underestimate cooling requirements. This is expected because economizer (outside) air in the simulated system is routed through reheat boxes whereas the building system doesn't route the air that way.

B. The triple-deck multizone system was designed for a building with significant outside air requirements in limited areas and diversity of hours of use and requirements. This system contains a third duct (in addition to the hot air and cold air duct) which allows mixed air to bypass the heating and cooling coils. This system type is not available on DOE-2.1D. It was simulated on DOE-2 as the Powered-Induction-Unit (PIU) system. The PIU system was chosen in order to minimize HVAC energy consumption.

In terms of minimizing energy use the PIU system was the most attractive. In terms of simulating the actual system design a PIU system operates differently than a triple-deck multizone system. (The *1992 HVAC Systems and Applications ASHRAE Handbook* contains a short discussion of the triple-deck multizone system.)

2. Number of HVAC systems and/or zones exceeds the simulation program limits.

Large buildings should be the focus of hourly energy simulation software. The types of HVAC systems and the importance of cooling calculations make large buildings fit hourly simulations. Unfortunately, large office buildings usually have multiple zones and HVAC systems that exceed limits set by energy simulation programs.

For example, office buildings are typically zoned with at least three interior zones (one general office area, one conference room/area, and one mechanical or other area), four perimeter zones (one for each ordinal direction), and one plenum zone for a total of at least eight zones/floor. DOE-2.1D has a constraint of 64 zones/building (reference 3). Then for the typical office building only eight distinct floors can be input (8 zones/floor x 8 floors = 64 zones).

Most larger office buildings have more than three interior zones (computer rooms and enclosed offices) and more than four perimeter zones (enclosed window offices and conference/meeting rooms). It might be important for the simulation to model these zones for example when modeling daylighting controls or occupancy sensor controls.

Floor-by-floor systems in high-rise office buildings can also be difficult to model for similar reasons. If input is limited to eight floors of zones then only eight systems can be input to heat and cool them. System energy can't be multiplied, like zone loads. System energy has to be calculated over all zones. So, for example, a 24 story high-rise office building with eight zones/floor and floor-by-floor VAV air distribution, and central chilled water and hot water plant, might be modeled in the following way:

> construct a set of zones for the ground floor, construct a set of zones for the typical middle floor (with a multiplier of 22), construct a set of zones for the top floor (total zones around 25), input a VAV system for each set of zones (ground floor, middle floor, and top floor) - a total of 3 systems, input a central plant to serve the three VAV systems.

To maximize the number of HVAC systems the building might be modeled another way:

> construct a set of zones for the ground floor, construct a set of zones for the typical middle floor, input the typical middle floor 6 times (twice with a multiplier of one for the zones next to the ground and top floor, and 4 times with a multiplier of 5). construct a set of zones for the top floor (total zones around 25), input a VAV system for each set of zones (ground floor, the six middle floors, and the top floor) - a total of 8 systems, input a central plant to serve the eight VAV systems.

Or, one could assume that all zones are served by a single system. This would simplify input further and might result in answers reasonably close to the other options.

Any of these solutions will probably be acceptable. One needs to consider the importance of zoning on potential ECM's, existing building energy use, and the difference in energy use between HVAC systems being combined.

Discounting numeric limits on energy simulation inputs, modeling high-rise office buildings as having multiple, typical floors makes input easier. The accuracy of results is subject to acceptance of the assumption that the energy use is constant for all middle floors. In a downtown area with shading and reflecting surfaces provided by surrounding buildings of varying height and location the solar components of heat gain and lighting contributions are compromised. The importance of this compromise should be evaluated on a case-by-case basis.

3. Multiple chillers of different size and efficiencies.

Large office buildings commonly have more than one chiller. Although DOE-2 allows multiple equipment types, it does not allow assignment of equipment to specific systems. In addition, only one part load curve can be input for each equipment type (reference 3, PART-LOAD-RATIO command). One has to estimate loads on specific chillers and try to match that load to specific chillers thru the LOAD-ASSIGNMENT command.

A situation found in large office buildings in Portland concerns having a double bundle chiller dedicated to a computer center for cooling and providing hot water to the building hot water loop. In this instance, users of DOE-2.1D are unable to assign the double bundle chiller to the computer center (except through the estimated load). The heat recovered from the double bundle chiller is then used to satisfy the heating load of the building.

Multiple chillers of different capacities are limited to sharing the same part-load curve and efficiency rating. For some large office buildings (buildings with one or more large chillers and one or more smaller chillers) this limitation might be important.

4. New and innovative HVAC control systems.

Automatic room temperature and lighting controls found in new control system specifications exceed the limits of energy simulations and require gross assumptions by the modeler. An example of this type of control strategy is TRAV (short for Terminal Regulated Air Volume).

TRAV is a DDC-implemented building control system that saves energy by keeping central fans running 24 hrs/day, integrating lighting with HVAC control, installing a space temperature sensor in every office, eliminating VAV box maximum and minimum air flows, and using the DDC operators' console as an electronic drawing file. This control scheme is discussed in detail in reference 4.

The TRAV control minimizes variable air volume fan energy consumption, even though central fans are programmed to run even during unoccupied hours. The unoccupied run time energy is minimized by operating the fan at minimum CFM's below 20% of maximum CFM's. Exterior zone heating requirements, during unoccupied hours, are met by parallel fan-powered terminal units. The building is always maintained at a closer temperature tolerance than would otherwise be the case, but overall energy is reduced.

Modeling this control scheme accurately would require detailed knowledge of occupancy schedules (by office) and the ability to input multiple distinct zones (see number 2 above) with associated schedules for occupancy, lighting, and temperature.

An example of input modifications for simulating TRAV on DOE-2.1D is provided in Figure 1. Not all changes necessary to fully simulate TRAV implementation are shown. This implementation of TRAV was primarily based on information provided in reference 6.

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SUMMARY

Most large office buildings contain situations that the typical energy simulation program does not specifically address. This paper presented solutions to some of these situations when using the DOE-2.1D building energy simulation program. These solutions were used in building energy studies performed over the previous three years.

REFERENCES

1. Private correspondence with Karl Johnson, Electric Power Research Institute, 1994.

2. Kaplan, Michael and Caner, Phoebe. *Guidelines for Energy Simulation of Commercial Buildings*, Bonneville Power Administration, 1992.

3. *DOE-2 Reference Manual (version 2.1C)*, USDOE, 1984.

4. Hartman, Thomas. *Promising Control Innovations with New Generation DDC*, Heating/Piping/Air-Conditioning, November 1992, pp 55-59.

5. *DOE-2 Basics*, Simulation Research Group, Lawrence Berkeley Laboratory, August 1991.

6. Private correspondence with Michael Hatten , Hatten/Johnson Associates, 1992.

FIGURE 1: Sample DOE-2 Input Changes for TRAV Simulation

Base Model

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$ CENTRAL FAN SCHEDULE

FAN-1 = SCHEDULE  THRU DEC 31
          (WD) (1,6)      (0)
               (7,18)     (1)
               (19,24)    (0)
         (WEH) (1,24)     (0)   ..

$ SPACE TEMPERATURE SETPOINTS

COOL-1 = SCHEDULE    THRU DEC 31
 (WD)  (1,7) (90)  (8,18)  (75)  (19,24) (90)
 (SAT)  (1,9) (90)  (10,17) (75)  (18,24) (90)
(SUN,HOL)  (1,24)  (90)  ..

HEAT-1  = SCHEDULE     THRU DEC 31
 (WD)  (1,7) (62)  (8,18)  (72)  (19,24) (62)
 (SAT)  (1,9) (62)  (10,17) (75)  (18,24) (62)
(SUN,HOL)  (1,24)  (62)  ..

$ MIN. OUTSIDE AIR SCHEDULE
$  -999 SETS OUTSIDE AIR TO  SYSTEM REQUIREMENT

VENT-1 = SCHEDULE  THRU DEC 31
            (WD) (1,6)   (0)
                 (7,18)  (-999)
                 (19,24) (0)
           (WEH) (1,24)  (0)     ..

$ DEFAULT FAN CURVE FOR VSD CONTROL
$ ESTIMATED FROM CURVE IN USER'S MANUAL
$  DEFAULT-CURVE=CURVE-FIT
$         TYPE = QUADRATIC
$         DATA =  (0.0,0.20)   -   (fan volume, fan power)
$                 (0.3,0.10)
$                 (0.4,0.20)
$                 (0.5,0.25)
$                 (0.6,0.40)
$                 (0.7,0.50)
$                 (0.8,0.65)
$                 (0.9,0.80)
$                 (1.0,1.00) ..

$  SYSTEM INPUT (System-type = DDS)

VAV-SYS =          SYSTEM
         MIN-CFM-RATIO     =        0.30
         MAX-FAN-RATIO     =        1.10
         FAN-CONTROL       =        SPEED

         MIN-OUTSIDE-AIR   =        0.10
         ........... (continued)

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TRAV Model

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$ CENTRAL FAN SCHEDULE

FAN-1 = SCHEDULE  THRU DEC 31
          (ALL) (1,24)       (1)      ..


$ SPACE TEMPERATURE SETPOINTS
$  FLOATING DEADBAND/SHORTER OCCUPIED TIME

COOL-1 = SCHEDULE      THRU DEC 31
 (WD)  (1,7) (80)  (8,16)  (75)  (17,24) (80)
 (SAT)  (1,9) (80)  (10,16) (75)  (17,24) (80)
(SUN,HOL)  (1,24)  (80)  ..

HEAT-1  = SCHEDULE     THRU DEC 31
 (WD)  (1,7) (65)  (8,16)  (72)  (17,24) (68)
 (SAT)  (1,9) (65)  (10,16) (75)  (17,24) (68)
(SUN,HOL)  (1,24)  (65)  ..

$ MIN. OUTSIDE AIR SCHEDULE
$ -999 SETS OUTSIDE AIR TO SYSTEM REQUIREMENT

VENT-1 = SCHEDULE  THRU DEC 31
            (WD) (1,6)   (0.01)
                 (7,18)  (-999)
                 (19,24) (0.01)
           (WEH) (1,24)  (0.01)     ..

$ FAN CURVE

TRAV-FAN = CURVE-FIT
         TYPE = QUADRATIC
         DATA =  (0.0,0.01)   $ (fan volume, fan power)
                 (0.3,0.025)
                 (0.4,0.08)
                 (0.5,0.12)
                 (0.6,0.26)
                 (0.7,0.39)
                 (0.8,0.58)
                 (0.9,0.78)
                 (1.0,1.05) ..

$  SYSTEM INPUT (System-type = DDS)

VAV-SYS =          SYSTEM
         MIN-CFM-RATIO     =        0.01
         MAX-FAN-RATIO     =        1.25
         FAN-CONTROL       =        FAN-EIR-FPLR
         FAN-EIR-FPLR      =        TRAV-FAN
         MIN-OUTSIDE-AIR   =        0.07
         ........... (continued)

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Table 1: Summary of Large Office Building Modeling Problems

Modeling Problem	Example	Modeled As:	Inaccuracies
1. Heated and cooled by systems not available in Simulation.	Dual Duct/ Dual Fan VAV.	VAV with terminal reheat.	Overestimates heating and underestimates cooling during mild weather conditions.
	Triple Deck Multizone.	PIU system.	Different system model, but similar energy use (low).
2. Number of HVAC systems and/or zones.	24-story office bldg. with 8 zones/floor & floor-by-floor VAV systems.	A set of zones for ground floor, typical middle floor, top floor, each with own VAV system.	Effects of surrounding shading and reflecting surfaces on lighting and solar energy is compromised. Energy use of floor-by-floor systems is combined into single system for middle floors.
	24-story office bldg. with 8 zones/floor & floor-by-floor VAV systems.	A set of zones for ground floor, six typical middle floor zones, one top floor zone, each with own VAV system or single VAV system for entire building.	Effects of surrounding shading and reflecting surfaces on lighting and solar energy is compromised.
3. Multiple Chillers	Large office with computer center cooled by dedicated chiller. Remainder of building cooled by same type of chillers, but of different size and efficiency.	Use LOAD-ASSIGNMENT command to match computer center chiller to computer center cooling load. Default curves for part-load of all chillers, and input rated EIR's of building chillers.	Chillers of different sizes and manufacture have different part-load curves and EIR's.
4. New and innovative control systems.	Terminal Regulated Air Volume (TRAV): - integrated lighting and HVAC controls - space temp. sensor in every office - no VAV box min or max airflow limits - fans run 24 hrs/day.	Input fan schedule as 24 hours/day, input revised zone heating/cooling setpoint schedule to model building' temp. as "floating" during unoccupied periods, input custom fan curve to simulate low loads associated with partial occupancy and unoccupied periods, set MIN-CFM-RATIO to 0.01.	Accurate modeling of this control scheme would require detailed knowledge of occupancy schedules (by office) and the ability to input multiple distinct zones with associated schedules for occupancy, lighting, and temperature.