THE DOE–2 USER NEWS

DOE-2: A COMPUTER PROGRAM FOR BUILDING ENERGY SIMULATION

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☞ ☞ HANDS ON ☜ ☜

☞ Inflate Before Ordering!!

Before you order more documentation, please check the back cover of this USER NEWS for new prices. Every January, the National Technical Information Service "adjusts" the prices of DOE-2 documentation.

☞ Directory of Services

DOE-2 has generated program-related software and consulting services which are listed on the inside back page of this newsletter. Please let us know of any updates or corrections.

This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Buildings and Community Systems, Buildings Division, of the U. S. Department of Energy under Contract No. DE-AC03-76SF00098.

☞ Time To Make Travel Plans

Aug 27-Sept 1 — *Second World Congress on HVAC*

to be held in Sarajevo, Yugoslavia.
Sponsors: ASHRAE; the International Council for Building Research, Studies and Documentation; and the International Institute of Refrigeration. Contact Dr. E. Kulic, Univerzitet u Sarajevo, Masinski Fakultet, 66, Omladinsko Setaliste, YU-71000 Sarajevo, Yugoslavia.

*

Sep 12-14 — *Eleventh Annual Industrial Technology Conference*

to be held in Houston, Texas.
Sponsors: Texas A & M University and the Louisiana Department of Natural Resources. Contact: Texas A & M University, Department of Mechanical Engineering, College Station, TX 77843.

*

Oct 24-28 — *Twelfth World Energy Engineering Congress*

to be held in Atlanta, Georgia.
Sponsor: Association of Energy Engineers and the Alliance to Save Energy. Contact: Association of Energy Engineers, 4025 Pleasantdale Road #420, Atlanta, GA 30340. Phone: (404) 447-5083.

*

Feb 11-14, 1990 — *ASHRAE Winter Meeting*

to be held in Atlanta, Georgia.
Contact: ASHRAE, 1791 Tullie Circle N.E., Atlanta, GA 30329. Phone: (404) 636-8400.

SIZING COOLING SYSTEMS WITH DOE-2

by

Bruce E. Birdsall

INTRODUCTION

Among DOE-2 users there are younger professionals who have never questioned how things were done in the "old days", i.e., before computers or DOE-2. Because problems like the sick building syndrome and inadequately sized systems are so prevalent in modern buildings, the purpose of this article is to outline some of the things "you should know" when using DOE-2 for sizing, and some history on sizing methodology.

A number of trends have occurred in cooling load calculation methods in the last forty years. The first was the ever-improving accuracy of the calculation to remove the "fat". Second, was the change to a selected apparatus dewpoint (rather than the intersection of the sensible heat ratio line and the saturation line). At the same time, building peak sensible loads have undergone a substantial reduction because of better insulation levels, better glazings and window treatment, and significant reductions in lighting levels from 4 watts/sqft in the 1960's to the present design level of about 1.5 watts/sqft. Credit for daylighting reduces the calculated peak sensible cooling loads even further. All of these factors combined can easily result in design air flows of 0.5 CFM/sqft, where not many years ago 2.0 CFM/sqft was not unusual.

The major problem in using DOE-2 for sizing purposes results from the assumption that an accurate constant temperature load calculation can automatically determine a system capacity sufficient to accommodate a startup load -- when, in fact, it doesn't. Consider the startup load as being composed of two parts, the normal daily load plus the load due to heat stored during the off period. With the daily load decreasing relative to the startup load (which has remained constant), the peak load of our modern buildings is now strongly driven by the stored load. The size of the stored load has increased since it is a function of the number of hours that the AC systems are off. Instead of 14 operating hours daily plus half-days on weekends, it is now typical for office buildings, for example, to have have 10 operating hours daily and none on weekends and holidays.

To clarify why a designer's perspective on sizing depends on his/her age, we show in the following how sizing calculations were done 1957, 1967, and 1977. The methods described are those that would be found in the ASHRAE Handbook of the time. The "Example Building" referred to is the ASHRAE example, which is unchanged since 1957.

COMPARISONS OF SIZING METHODS

The 1957 method is commonly referred to as the **Steady State Calculation Method.** This is the most simple manual method and is still used for small commercial buildings and residential calculations. It has the following characteristics:

- An instantaneous sensible load that includes fan heat as a space load. This tends to provide the highest estimate of sensible gains and air flow requirements. The ASHRAE Guide estimated that sensible heat for the Example was 205kBtuh.
- An engineered selection of the cooling coil leaving air temperature based on the Sensible Heat Ratio (SHR) which provides conservative estimates of cooling coil capacity and system air flow.

The 1967 method is commonly referred to as the **Two Step Method**. The original APEC HCC-II program used this method. It was computerized primarily due to the time required to make the calculation manually. This method has been re-introduced in the 1989 ASHRAE Handbook. It has the following characteristics:

- Instantaneous sensible loads averaged over the previous five hours, plus a split of purely convective and radiative heat gains. This provides a more dynamic estimate of sensible loads compared to the 1957 method. The ASHRAE-estimated sensible heat for the Example was 189kBtuh.
- Fan heat is not accounted for in the load itself, which contributes to lowering the sensible estimate; however, the ASHRAE Systems Handbook indicates how fan heat should be accommodated.
- Arbitrary selection of Apparatus Dew Point (ADP) and, thus, the cooling coil leaving air temperature. This allows a liberal estimate of the total heat (sensible + latent) removal of the cooling coil.

The 1977 method consists of a "Simplified Procedure" and a "Weighting Factor Procedure", described as follows:

(1) The Simplified Procedure is commonly referred to as the **One Step Method.** Most engineers have computerized the procedure using a spreadsheet. Programs such as ASEAM and TRAKLOAD use this method, which has the following characteristics.

   - The Cooling Load Factor (CLF) + Cooling Load Temperature Difference (CLTD) approach both simplified and improved upon the Two Step Method for estimating peak cooling loads, especially when calculated manually. However, the dynamics and load profile characteristics of the Two Step 1967 method were lost. The ASHRAE-estimated sensible heat for the Example was 152kBtuh.
   - Fan heat is accounted for by following the recommendations in the ASHRAE Systems Handbook. Most computer programs based on this method do add fan heat into the total heat capacity of the cooling coil.

- Arbitrary selection of ADP is used, allowing for a liberal estimate of the total heat removal of the cooling coil.

(2) The Weighting Factor Procedure is commonly referred to as the **Hour-By-Hour Method.** DOE-2 and ESP-II use this method since it provides an accurate estimate of the total heat removal of the cooling coil. (BLAST and TRNSYS use an hour-by-hour detailed heat balance method which in some cases is even more accurate than the Weighting Factor Method for calculating loads.)

- Cooling loads are calculated using wall response factors and room weighting factors (Note: the CLF's and CLTD's were derived using this method). The complexity of the method requires a computer. The load is dynamic with respect to sun position, ambient conditions, and internal gains, but loads are calculated at a constant space temperature.
- Fan heat is accounted for in all computer programs.
- Automated sizing procedures do use arbitrary selection of the ADP; however, the simulation calculates the space sensible load and the moisture gain in the space for each hour and thus negates the oversizing aspect of using the selected ADP alone.

HOW DOE-2 AFFECTS SIZING RESULTS

DOE-2 Design Cooling Load

As mentioned in the previous section, DOE-2 calculates the design cooling loads using the most recent recommendations found in the ASHRAE Handbook of Fundamentals. This is the Weighting Factor Method used in the LOADS portion of the program. In SYSTEMS, DOE-2 then takes the sensible loads calculated in LOADS and proceeds to calculate design air flows, design fan heat, ventilation and infiltration loads, and finally, coil cooling capacity (adjusted to ARI rated conditions of 80DB 67WB in the space). This information is reported in Verification Report SV-A, and should be thought of as an upper limit on the cooling coil capacity for the simulation that follows.

When the DOE-2 Design Day routines are used, everything is much the same as described above except that in lieu of using data from the weather tape, the design conditions of drybulb, wetbulb, cloud cover, etc. are user-specified for the LOADS calculation. In SYSTEMS, the sensible loads from the Design Day are used in the sizing routines; however, the hourly simulation uses only weather tape data, and it is the maximum sum of these coil loads that is passed to PLANT for auto-sizing of chillers and boilers.

We should mention that fan heat is not considered a space load, as this would increase the air delivered to the space. For a draw-through unit, the cooling coil leaving air temperature is depressed by an amount equal to the fan heat ΔT, which allows the design supply air temperature to satisfy the space temperature. All of the energy that represents losses due to inefficiencies of the motor, fan drive, and fan itself is considered an additional load on the cooling coil. For a blow-through unit, the supply air temperature is not depressed, but the heat gains associated with the fan are added to the coil load.

The DOE-2 SYSTEMS Hourly Simulation

The hourly simulation is very complex and we will stress only those portions that affect this discussion. Understanding these elements should make it possible for anyone to see why designers using DOE-2 should be very careful, especially when sizing thermal energy storage (TES) systems. After comparing the manual calculation procedures with this background discussion of DOE-2, it should be apparent why the manual methods have built-in safety factors that usually go unnoticed.

For purposes of this discussion, let us assume that we have a variable air volume system (VAV). At the point that the air leaves the air handling unit, it is at the specified supply air temperature, which in DOE-2 is MINIMUM–SUPPLY–T. This air is simulated as entering the space and satisfying the room thermostat setpoint, as specified by COOL–TEMP–SCH. If the space load is more than adequately met, the volume of air is reduced. If the space load is not met because the sensible load is greater than the sensible coil capacity, the space temperature is allowed to float upwards, and a *load not met condition* is reported. Concurrent with the above, a moisture balance is calculated that accounts for the moisture added to the space by internal latent gains and infiltration air, or by ventilation air bypassing the cooling coil. This allows DOE-2 to calculate the humidity ratio and relative humidity of the space, which tend to be much lower than design conditions would dictate due to the arbitrary selection of the ADP. The total cooling coil load can be calculated as the difference between the mixed air enthalpy and coil leaving air enthalpy using the equation:

$$Q_c = CFM * 4.5 * (H_{mix} - H_{leav})$$

The value for the cooling coil load includes heat added to the return air from lighting fixtures and return fans. H_{leav} is the specific enthalpy of the air leaving the cooling coil. It is a function of the the supply fan heat, the throttling range of the cooling coil controller, and the moisture removed by the coil. In DOE-2, the MIN–SUPPLY–T is read downstream of the supply fan and therefore is equal to the coil leaving temperature plus the depression necessary for the fan heat plus any depression due to the controller's throttling range. In the real world, the normal location for a controller is directly downstream of the cooling coil. It is wise to note this difference between real systems and a calculational compromise made in DOE-2.

The maximum total cooling coil load is determined for each hour that the fan is on and recorded along with the hour, day, and month it occurs. The startup load is calculated at the floated temperature that the space attained after any period with the fans off and includes moisture levels that are in equilibrium with outside ambient conditions. We can be reasonably sure that after a hot weekend the first few hours after startup will contain hours of "loads not met". The reason for this is that if automatic sizing is used in DOE-2, the coil capacity and design air flow will be based on a peak load calculated at constant space temperature. This peak load will usually be significantly less than the actual peak pulldown load, resulting in an undersized system. To avoid this problem, the user must intervene and adjust capacities in DOE-2 to handle the startup loads. A procedure for doing this is given below in "Suggestions on how to use DOE-2 reports and inputs to address system sizing tradeoffs".

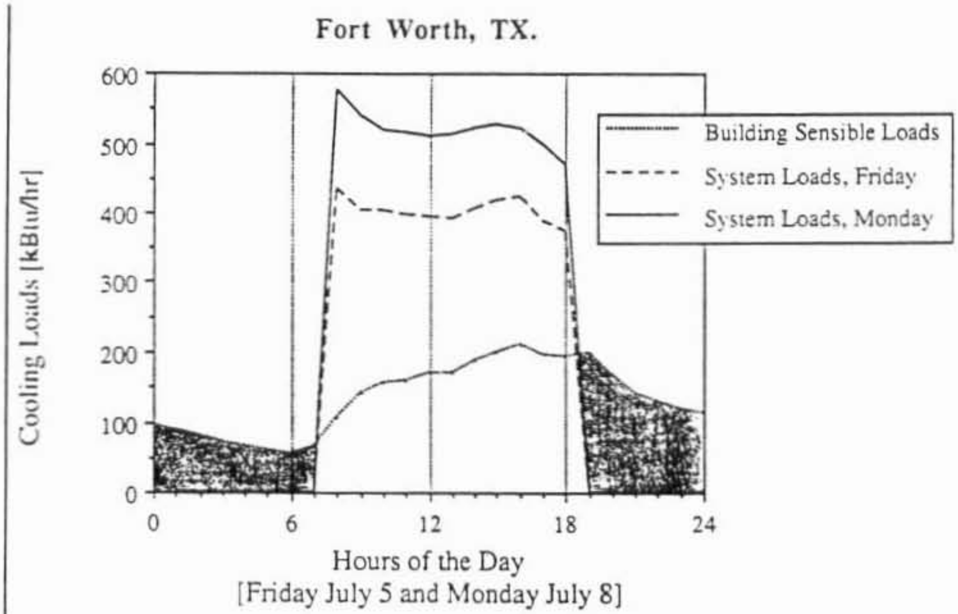
Another point that is not readily apparent and contributes to a shortage of capacity on startup is the result of all zones on the system calling for full air flow at startup time. If the system air has been sized for a building block load (DOE-2 terminology is COINCIDENT) rather than the sum of the zone peak air requirements (NON–COINCIDENT), then zone air is proportioned by each zone's requirement, divided by the total capacity available for all zones, and is thus short everywhere. This actually occurs in real systems because only after the zones most easily satisfied are cooled down does excess air go to the zones that have the largest pulldown loads.

RECAP AND SUGGESTIONS

In past years, our designs allowed us to ignore stored loads because the load estimates were much more liberal, coupled with the fact that the daytime loads themselves were much higher (resulting is higher air flows rates and system capacities). Under these circumstances, the stored load may have increased the normal load by only 5%. Today, on the other hand, the stored load may easily increase the normal load by 30%. An example of this is given in Figure 1. This shows the profile of the sensible load as calculated in the LOADS section of DOE-2, then as it appears when converted to a coil load in SYSTEMS on a Monday following a hot weekend, and then again on a Friday after cooling all week. Here are some suggestions of how you can check for these same effects when using DOE-2 for design.

Figure 1:

During a hot spell the building does not release heat at night. Therefore, the shaded areas, which represent the delayed heat gains, are not released and must be removed by mechanical cooling the next day.



DOE-2 inputs that contribute to *low* estimates of capacity at startup are as follows:

- Setting NIGHT–CYCLE–CTRL=CYCLE–ON–ANY (or CYCLE–ON–FIRST) will allow the fan to be simulated on during the weekend and thus remove the Monday morning startup load. Simulating fans as being on during the operating periods when the chiller is not available for cooling, such as the TES charging period, can lead to false readings of the peak integrated daily loads.

- Unrealistically high infiltration rates on nights and weekends will cause a simulated dilution of heat gains that otherwise would be stored.

- Use of the DESIGN DAY feature with a selection of DB and DP temperatures or cloud cover and clearness values unrepresentative of peak conditions. Some types of weather tapes may also present similar problems.

- Simulating a one-story building with a return air plenum and failing to use the SIZING–OPTION=ADJUST–LOADS feature. Since the plenum roof load is assigned to the return air, the supply air flow to conditioned spaces is missing the sensible roof gain. This can result in less than adequate capacity to handle the startup load.

DOE-2 inputs that contribute to *high* estimates of coil capacity are as follows:

- Simulating a building without specifying internal walls or specifying internal walls as adiabatic, results in unrealistically high space temperatures when fans are off. The reason is that there is no simulated heat release from the interior spaces and this will, in turn, affect the startup loads as simulated space temperatures are excessive.

- Simulating the air system with a high economizer limit temperature results in the economizer being open at the design peak. This can result in a cooling coil capacity based on cooling 100% outside air close to saturation, thus giving a very high false reading of peak integrated daily loads.

Suggestions on how to use DOE-2 reports and inputs to address system sizing trade-offs:

- SYSTEMS Report SS-F indicates the maximum temperature at startup and the number of hours each zone exceeds the thermostat setpoint.

- SYSTEMS Report SS-O shows temperature bins and the hours that the zone temperature falls within each 5°F bin. It gives a good indication of how well the system performs during normal operating hours.

- SYSTEMS Hourly Reports showing a 24-hour profile of zone temperatures for a few sample zones (interior and perimeter spaces) on the peak day (as reported in SYSTEMS Report SS-J) is the best source of information indicating how long it takes before space temperatures are satisfied.

- For cases where the number of hours of "loads not met" is higher than acceptable, we suggest that you increase system size in increments, either by setting DESIGN–COOL–T = <lower value>,
or by setting SIZING–RATIO= <higher value>.

- For cases where some other means has been used to establish air flow rates for each zone, input those flow rates using ASSIGNED–CFM, then use a DOE-2 run as a check on the dynamics of system operation.

- For cases where you are interested in designing for "worst case" ambient temperatures, edit the weather tape using the DOE-2 Weather Utility Program* and enter a series of days overlapping a 3- or 4-day weekend. A series of days representing a hot spell will generally give a much higher peak integrated load than an isolated peak day.

- To observe the effect of operating strategies that mitigate the most severe situations, try starting the systems earlier in the morning for a conventional system or on the previous day for a TES system where early operation would deplete the storage.

* see *User News*, Vol. 7, No. 3 for a description of the Weather Utility Program.

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DOE-2 SOFTWARE AVAILABILITY

DOE2.1C software packages are available from the National Energy Software Center (NESC) for the DEC VAX 11, DEC 10, IBM 3083, and CDC 7600 computers. These software packages include machine-readable source, sample problem input and output, and auxiliary routines and information as well as hard-copy documentation.

The DOE2.1D replacement edition for the DEC VAX 11 is expected to be available in September 1989.

As the centralized computer software management facility for the U. S. Department of Energy and Nuclear Regulatory Commission, NESC's primary functions are to promote the sharing of software among agency offices and contractors and to serve as the focal point for disseminating agency-sponsored software to private industry, the public, and foreign requestors. Today, the Center's software library consists of over 1500 computer programs and data compilations contributed by authors and software developers, submitted in compliance with agency contracts, or solicited by the Center in response to requests received. All software is licensed to the requesting individuals and organizations for their use only and is not to be copied and given to or used by others. Users of NESC software are notified of corrections or replacement editions when they become available.

To obtain more information on this or other NESC software, contact:

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