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* * * HANDS ON * * *

☞ **Program Tapes** — Please call or write us at LBL for details on how to obtain DOE-2.1C.

☞ **Problems with the IBM Version of DOE-2.1C?** Several users have encountered a problem installing DOE-2.1C on IBM VM/CMS operating systems. It is claimed that this operating system has an upper limit of 32K bytes per record for disk files. Since several DOE-2 files (keyword file, edit table, standard file for large buildings) have records longer than this, the implementation cannot proceed. Other users using MVS/XA and VM/CMS have reported no such problems. Please contact us if you know of a solution to this problem!

☞ **DOE-2, Please Phone Home !!** — The editorial staff of the User News welcomes feature articles that would be of interest to DOE-2 users. If you would like to make a contribution to the "News" (two or three printed pages is the right length), won't you please send an article to the editor?

[*The following article was written by Leslie Jones and Douglas B. Gray of LESLIE JONES & ASSOCIATES, INC., Ottawa, Canada. It is being printed here because we feel that the contents will be of interest to a large number of DOE-2 users. If you have written an article you would like published in the USER NEWS, please send it to us.*

This article is specifically aimed at users of DOE-2.1B. It does not apply to users of DOE-2.1C, since most of the limitations in DOE-2.1B for modelling atrium buildings have been eliminated in DOE-2.1C, the latest version of the program. Some of the atrium-related capabilities of DOE-2.1C which are lacking in DOE-2.1B are (1) automatic calculation of solar gain into atrium-facing spaces, taking into account self-shading by the atrium walls; (2) mechanical or natural ventilation of the atrium; and (3) use of the atrium as a return-air plenum. These and other features of the DOE-2.1C simulation are described in "Sunspaces", pp. 2-1 to 2-32 of the **DOE-2 Supplement, Version 2.1C**, *which is available from NTIS (see the inside back cover of this newsletter). One important atrium feature which DOE-2.1C cannot directly handle is the calculation of daylight levels in atrium-facing spaces. In cases where such daylighting is an important consideration, we recommend making illuminance measurements in scale models and entering the measured daylight factors into DOE-2.1C using "Function Values" (see pp. 1-2 to 1-14 of the* **DOE-2 Supplement, Version 2.1C**; *in particular, see Example 4 on p. 1-8). Please call or write us at LBL for details on how to the obtain DOE-2.1C version of the program.*]

PUB-439

MODELLING ATRIUM BUILDINGS USING THE DOE-2.1B BUILDING ENERGY SIMULATION MODEL

by

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ABSTRACT

As more and more designers are turning to atrium building solutions to produce visually interesting and low energy use buildings, engineers are being called upon to investigate the building's potential energy performance and to develop systems that enhance or capitalize on their inherent thermal and visual characteristics.

This is a particularly challenging task given that most software currently available is not explicitly designed for the rigorous analysis of such buildings. With some perseverance and cunning, however, existing software can be used to model some of the complex energy flows occurring in an atrium building. This paper describes how the DOE-2.1B Building Energy Simulation Model was put to such a task.

INTRODUCTION

In January 1984, the Division of Energy of the National Research Council of Canada (NRCC) commissioned Leslie Jones & Associates to carry out an assessment of atrium buildings. The primary focus of the study was to determine the impact of atrium design strategies on building energy efficiency, particularly as it relates to the collection and utilization of solar energy.

The project was completed and a report was published in December 1985, which included a general discussion of atrium design issues, results of detailed evaluations of a number of these issues, a cost study comparison, and a section devoted to describing modelling techniques used in the study. Extracts from the section dealing with modelling are presented in this paper; a complete description of the project (report No. Passive-12) can be obtained from the NRCC.

MODELLING TECHNIQUES

Modelling of atriums and buildings containing atriums presents a particularly difficult challenge to the energy analyst. To our knowledge, there is no program that can currently handle the wide range of possible design issues that the architect or engineer might wish to address. However, existing software can be applied to the analysis of atrium buildings by either ignoring some of the building complexities, using "engineering judgment", or by looking at ways of using the software to get the desired result, albeit if by some roundabout manner.

Of course, one could treat atriums and atrium buildings in the same manner that we might look at conventional building spaces; however, such an approach fails to make use of the atrium in a constructive, energy saving, or innovative manner.

Ignoring some of the complexities involved in a problem is often applied quite acceptably, where the complexities are known to have only a small impact on the overall result. The difficulty in applying such a philosophy to atrium buildings is that there is a general lack of widespread atrium modelling experience; thus, deciding what is and what is not important becomes somewhat arbitrary. A similar argument can be made about engineering judgment — energy models have been developed to assist and develop engineering judgment in the very complex area of building energy analysis and the use of such detailed models can be expected to *precede*, not follow, engineering judgment.

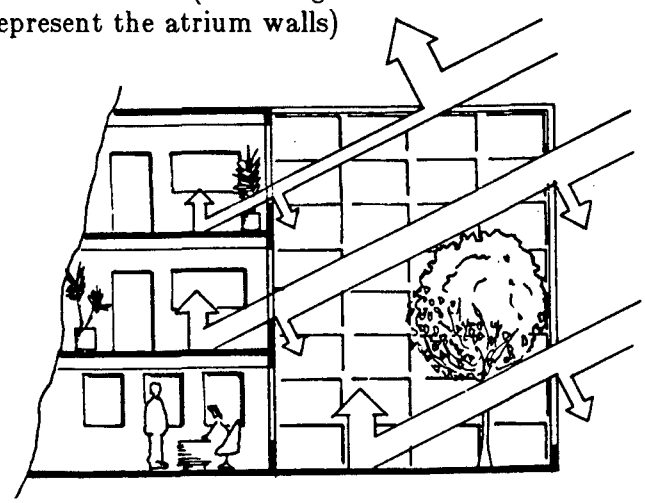
One is left then with trying to make the best use of available software if one wants to carry out a serious analysis of atrium building design. For our own modelling purposes we chose to work with the DOE-2.1B program primarily because of our own familiarity with the software and our knowledge that it would probably satisfy a large number of our requirements. The way in which the software package was used to analyze a number of key atrium design issues is described in the following text.

Modelling the Distribution of Solar Radiation

The basic problem complicating the modelling of the atrium buildings stems from the self-shading effects of the building geometry. This is particularly the case where one wants to consider solar radiation passing through the atrium space into the adjoining space, as illustrated in Figure 1.

Attempts to simulate a four-sided atrium building as a single model, that is with the walls in each zone comprising the model being alternatively a **shading** surface and a **shaded** surface, not only proved to be extremely complex, but also resulted in an output that was, obviously, not correct.

Figure 1: Solar Radiation Flows Through the Atrium ("building-shades" are used to represent the atrium walls)



To circumvent this problem, the building must be broken down into several independent models. However, this does not allow for heat transfer between zones which is a concern where adjacent spaces are at significantly different temperatures.

A further simplification can be considered if the effects of solar entering the space adjoining the atrium are considered to be unimportant. In such an instance, the building need not be described as geometrically "correct", and the effect of self-shading can be ignored (in which case glazing between the atrium and the adjoining space would essentially become interior partitions). Such an approach might be considered where: (1) the atrium, or wall between the atrium and the main building, is not extensively glazed; (2) shades are installed to prevent penetration of solar into the main building; (3) the geometry of the atrium itself precludes any significant solar penetration (e.g., deep and narrow atrium spaces); (4) daylighting strategies are not to be evaluated.

Also, where primary concern lies with *overall* annual energy consumption (excluding the atrium itself), then it is often reasonable to ignore the effect of solar radiation passing through the atrium into the main building. This is particularly true where the area adjacent to the atrium is small compared to the total area of the main building. The area adjacent to the atrium typically represents less than 30% of the main building floor area. While the component energy breakdown (i.e. heating, cooling, fans,

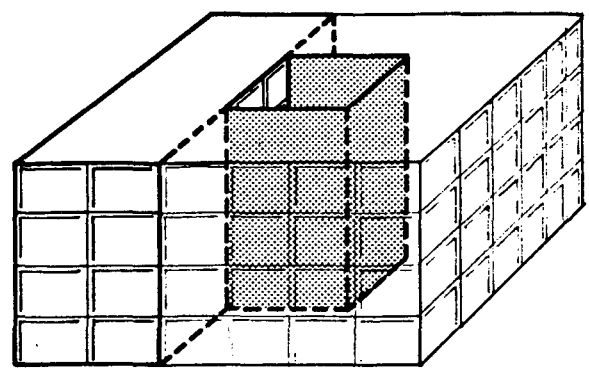
etc.) will not be as accurate with this method of modelling, it is expected that the estimated total energy consumption will be within 10% of the consumption calculated by the more complex method.

However, when the analyst is interested in component energy consumption, peak loads, daylight illuminance or glare in individual zones facing into the atrium, then it becomes necessary to try and model solar energy flows. In doing so there are two main aspects to consider: the flow of radiation into the building adjoining the atrium space, and the amount of radiation remaining in the atrium space itself.

Solar Gains and Daylighting in the Spaces Adjoining the Atrium

It is relatively easy to model a space facing into an *unenclosed* atrium (i.e., an open courtyard) by describing the surrounding atrium walls as "external shading" using the BUILDING SHADE command (see Figure 2). It is necessary, as previously mentioned, to construct the building model as a series of separate independent models. Such a step, however, severely limits the system and central plant modelling options.

Figure 2: Modelling Self Shading ("portion of building being modelled")



Modelling a space facing into an *enclosed* atrium is much more difficult, since solar radiation passing into the adjoining space must first pass through the outer atrium glazing. The most simple solution to this problem is to consider the combined transmittance of the glazing layers; however, this is only reasonable if the glazing surfaces are parallel to one another. One way of modelling the varying transmission of two non-parallel glazings is to represent the transmission characteristics of one of the layers of glass by a SHADING-SCHEDULE, which represents the changing transmission characteristics of the atrium glass with hourly and seasonally changing sun angles.

The values in the SHADING-SCHEDULE can be calculated for each "sun up" hour of twelve design-days, representing an average day in each month.

For each design day, hourly values of solar energy incident and transmitted through each "window" are output from a DOE-2.1B model describing only the atrium glazing. (Window VARIABLE-TYPE, VARIABLE-LIST numbers 11, 12, and 15.) The fraction of the incident solar energy that is reflected off the atrium glass is then calculated as

$$1 - \frac{\text{transmitted solar}}{\text{incident solar}}$$

Modelling the solar radiation entering into the adjoining space through an *enclosed* atrium can be achieved by setting up a model in a similar manner as one would for an *unenclosed* situation, by applying the derived SHADING-SCHEDULE to the windows facing into the atrium. Because these windows are not exposed to outside temperatures, the U-value should be set to a very low value to give very low (negligible) heat transfer rates. (This implies that the atrium is maintained at the same temperature as the adjoining building.) Avoid using zero, though this would be the correct value where the temperatures are identical, since zeros can often create unexpected errors in computation.

The distribution of daylight can be handled in a similar manner as the solar energy. The same schedule is referenced at each atrium-facing window as a visible transmission schedule (VIS-TRANS-SCH) and is used to reduce the amount of daylight each area receives as a result of daylight reflected off the atrium glass.

Additional complications occur when one wishes to simulate movable or variable transmission devices, since only a single set of SHADING-SCHEDULEs can be accommodated at one time. An idealized form of shading in which the shades are lowered whenever there is a cooling load and raised when there is a heating load can, however, be evaluated by running the model twice: first without shades and then with shades. The with-shades model is described by modifying the window glass shading coefficient of the without-shades model. The heating energy consumption can then be taken from the without-shades run and the cooling from the with-shades run. In those spring and fall months when there is both a heating and cooling load, the electrical energy consumption (lights, fans, etc.) can be averaged between the two runs. Otherwise, the electrical energy is taken from the without-shades run during the winter months and with-shades run during the summer.

Solar Gains and Daylighting in the Atrium

The amount of solar energy staying in the atrium can be difficult to model since some solar will pass directly through to the adjoining building. The analyst can approximate the amount staying in the atrium using a method similar to that which was described above. In this case, however, models are first constructed for each of the windows in the zone between the atrium and the adjoining space in order to calculate the amount of solar that would be transmitted into the adjoining space. The atrium is assumed to be unenclosed.

A simple model of the atrium is run in order to determine the amount of solar energy incident upon the atrium glazing. The fraction of solar energy that is incident on the atrium glass, and stays in the atrium, can then be calculated from the hourly output of the above models; i.e.,

$$1 - \frac{\text{solar energy transmitted through all atrium-facing windows}}{\text{solar energy incident on the atrium glass}}$$

The atrium is set up as a normal single-zone model except that a SHADING-SCHEDULE based on the fractions calculated above is applied to the atrium glazing.

To model daylight levels in the atrium space it is not necessary to go to such complexity; weighted average reflectances can be specified for the walls to the adjoining spaces. The glass in these walls can be expected to have a reflectance in the range of 5% to 15%.

Movable shading devices may be approximated by the same method used in the previous section by modifying the window glass characteristics and running the model twice: once with shades and once without shades.

Thermal Zoning

As with all types of buildings, the question of splitting the building down into thermal zones for the purpose of simulation is one which deserves careful consideration. In atrium buildings, the fact that there are varying degrees of self-shading on the atrium-facing spaces tends to suggest a need for breaking the atrium-facing spaces down into a large number of zones. Such a route, however, can create an enormous amount of work for the analyst and increase the potential for error.

If the analyst is primarily concerned with overall building energy consumption, it would be quite reasonable to simulate the atrium-facing zones on the basis of one zone per floor per orientation. For those floors with limited solar view (e.g. floors deep in the atrium, North facing, in small atriums or atriums with minimal glazing, or where daylighting is not a consideration) some grouping of floors would be appropriate. It should be remembered also that the atrium-facing zones normally only represent a small fraction of the total floor area of the building, which means that the impact of inaccuracies in the modelling of these zones will be reduced in the context of the overall building consumption.

Conversely, if the analyst is interested in hourly load information, daylighting, or glare in individual rooms or sections of the atrium-facing zones, then division into small zones is necessary. (Details of a sensitivity analysis to zoning are given in the original report.)

Modelling When the Atrium and the Adjoining Building are at Different Conditions

Unless the effects of daylight and solar radiation entering the spaces adjoining the atrium are **not** considered, heat exchange between the atrium and the adjoining space cannot be handled explicitly. There are, however, a number of techniques in which effect, such as omitting the atrium heating and cooling systems, can be investigated.

Unconditioned and Partially Conditioned Atriums

It is not possible to model the *complete* building in one simulation unless solar heat gains into the atrium-facing zones are ignored. It is possible, however, to determine the impact that the surrounding space has on the energy consumption and temperatures of the atrium while accounting for the solar gains. Likewise, it is impossible to determine the *incremental* impact of an unconditioned and partially conditioned atrium on the main building consumption.

This can be achieved by simulating the atrium and main building as two adjoining thermal zones: one zone being the atrium which is set up in the manner previously described and the other zone representing the space surrounding the atrium. This second zone need only be described as a simple interior space in order to minimize the amount of coding required. The conductance of the atrium-adjoining space partition walls needs to be described in order to account for heat transfer between two spaces.

If one wanted to access the impact of, say, having an unconditioned atrium, one would run the model twice: once with a fully conditioned atrium and again with the atrium unconditioned, from which the *absolute* energy consumption of the atrium and the *incremental difference* in energy consumption for the adjoining building could be obtained.

Mechanical Ventilation

Since, arguably, temperature control in the atrium space could be relaxed somewhat from that desirable in continuously occupied spaces, there exists a possibility of minimizing mechanical servicing costs by providing mechanical ventilation in place of air conditioning.

A desirable control strategy for such a ventilation cooling system would be to operate the fans whenever the space temperatures exceeded the desired space "cooling" setpoint and when the outside air is, for example, two to three degrees lower than the inside temperature. In addition, it might be considered desirable to subcool the atrium to, say, 15 °C, allowing the atrium to store cooling within its fabric to offset subsequent cooling demands.

DOE-2.1B is not able to model such a system directly; however, the capability of a mechanical ventilation system to limit atrium temperatures can be evaluated by running an atrium model, as previously described, with a fixed, continuous outdoor air supply rate and a "setpoint" temperature (Load's TEMPERATURE command) the value of which represents the lowest acceptable internal temperature below which the ventilation would be shut off. A constant "air change" rate in the infiltration command (INF-METHOD=AIR CHANGE & INF-CFM/SQ-FT) can be used to specify the outdoor air supply rate. Obviously, such a system would not be installed and operated in this manner and the heating consumptions from the simulation will be meaningless. The model does, however, allow the evaluation of the ventilation cooling system by providing atrium space temperature data.

Natural Ventilation

As an alternative, a designer may wish to use natural ventilation. The design problem here lies with the sizing of the ventilation openings needed to provide acceptable internal temperatures. The process is essentially an iterative one and the designer must first choose a ventilation opening size and carry out an analysis using this information. The results of this first analysis can then be taken as an indication of whether larger or smaller vents are appropriate.

Using DOE-2.1B in such a process presents a problem since the best available option for simulating natural ventilation in the program is to use the CRACK method option under the infiltration command. Although this method is sensitive to both wind and stack effects, it is not ideal for simulating natural ventilation. Furthermore, since the infiltration flowrate is calculated in the Loads portion of DOE-2.1B where the inside temperature is assumed to be constant, the simulation of stronger stack action following rising atrium temperatures is not possible.

To circumvent this, the model can be run a number of times, each time with a different Load 'setpoint temperature'. For instance, runs might be made with setpoint temperatures of 22 °C, 26 °C, 30 °C, and 34 °C. Hourly space temperature output from each of these runs can then be used to build up an interior space temperature bin profile by:

i) for the 34 °C run, adding up the hours that the temperature is between 32 °C and 36 °C

ii) for the 30 °C run, adding up the hours that the temperature is between 28 °C and 32 °C

and so on for the remaining runs. The method is not a rigorous solution and some hourly data tends to "fall between the cracks" in the runs, but the method should give the analyst some idea of the atrium's potential performance.

A further complication arises when trying to use the method suggested above because DOE-2.1B uses an "infiltration coefficient" to characterize a uniformly distributed wall leakage opening as opposed to accepting an absolute size and location of leakage opening. To get around this problem, an equivalent infiltration coefficient must be calculated that results in the same infiltration rate as the desired vent opening and location; the method given in Chapter 22 of the 1985 ASHRAE Book of Fundamentals can be used to calculate this.

Since a natural ventilation system would require some form of dampered opening to stop ventilation when it is not required, any evaluation of the potential benefit of natural ventilation should include analysis of the additional heating energy use likely to be created by damper leakage. This can be achieved by running a regular atrium model for the heating season with the leakage characteristics of the dampers characterized by an appropriate equivalent infiltration coefficient.

DOE-2 WEATHER PROCESSOR UPDATE

The DOE-2 weather processor program is a key part of the DOE-2 software. A large fraction of the questions our group receives have to do with weather data and use of the weather processor. Unfortunately, weather processor documentation has not received much attention and tends to be inadequate and out of date. We will try to remedy this with discussions of weather data and weather processor related questions in this and future issues of the USER NEWS.

The weather processor is described in the **DOE-2 Reference Manual, Vol. 2**, pages VIII.36 to VIII.43. The primary function of the weather processor is to read hourly raw weather data in a variety of formats, extract the data needed by DOE-2, and write a packed, binary weather file which is used by the DOE-2 simulation program. In addition to its primary function (which we call "packing"), the weather processor can edit (in batch mode) an existing packed file, produce an hourly listing of packed or raw weather files, and produce a summary report of the data on a packed weather file.

To execute the weather processor, the user must supply a small input file (called INPUT.TMP on the VAX-VMS system) which tells the program what function it is to perform, and supplies any additional information [such as the latitude and longitude of the weather station] that may be needed. An example of such a file is shown in the **DOE-2 Reference Manual, Vol. 2**, page VIII.41.

Several new and/or undocumented features of the packing process need to be mentioned. Starting with DOE-2.1B, monthly ground temperatures no longer have to be input. Instead, a soil diffusivity (ft^2/hr) is input in a new field (columns 61-66) of line 3 of the "packing" input (see below). The value .025 is a good default. On line 5, which normally contains the monthly ground temperatures, -999. should be entered in the first 5 columns. This acts as a flag to tell the weather processor to calculate monthly ground temperatures from monthly average air temperatures and the soil diffusivity. The algorithm used is from NBS. Note that a soil diffusivity **must** be input if this calculation is to take place.

Field 8 (columns 43-48) of line 3 is important. If a TRY or other raw weather file **without** solar data is being packed, this field should contain NORMAL. If a TMY or other raw weather file **with** solar data is being packed, this field should contain SOLAR. Failure to get this right will result in either: (a) having **no** solar during the simulation or; (b) having calculated (from the cloud cover data) instead of measured solar during the simulation.

If a file with solar data is being packed, the monthly clearness numbers (line 4) will not be used in the simulation. Therefore, the values input are unimportant. All 12 fields can be filled with 1.0.

To make this more clear, we show a typical input file for packing a TMY file, with the items just discussed included.

```
PACK
TMY   NASHVILLE, TN
TMY     13897   -999       6 36.1   86.7 30-BITSOLAR        4 20.   .025
1.0    1.0    1.0    1.0    1.0    1.0    1.0    1.0    1.0    1.0    1.0    1.0
-999.
LIST
PACKED   -999   -999       1    12
STAT
END
----+----1----+----2----+----3----+----4----+----5----+----6----+----7-
```

Hourly Listing and Statistical Summary

The listing and statistical summary features of the weather processor are very useful. They can be used by themselves; that is, they do not have to be used in conjunction with packing. The input to list a packed file is shown in the **DOE-2 Reference Manual, Vol. 2**, at the bottom of page VIII.41 ("cards" 6-9). In addition, it is possible to list most raw weather files. Below is the input necessary to list the raw TMY file for Detroit. Note that some additional input data is needed — the latitude, longitude and time zone.

```
LIST
TMY      -999 14822      1     12      5 42.42 83.02
END
----+----1----+----2----+----3----+----4----+----5----+----6----+----7-
```

The statistical summary should always be examined after a file is packed, in order to pick up any problems with the raw data. The statistical summary, an example of which is shown on pp. 10-12, can **only** be produced from a packed file. The input needed is just STAT (columns 1-4) followed by END (columns 1-3) on line 2.

Some new items have been added to the summary. Heating and cooling degree days and hours are shown for each month, for four different bases. A page of information on solar radiation has been added. This includes insolation on vertical surfaces with four different orientations. Lastly, note that the ground temperatures are given in Rankine units.

Executing the Weather Processor

Most users of DOE-2 have executed the weather processor at least once, in order to pack the Chicago TRY weather data supplied on the DOE-2 release tape. On VAX release tapes, this is step 8 in implementing DOE-2. On the 2.1C IBM tapes, it is step 5. This procedure file can be used as a model for packing other weather files. In terms of the file names used on the VAX, the steps are:

(1) copy the hourly raw weather file to WEATHR.TMP;

(2) copy the user's input to INPUT.TMP;

(3) execute the weather program;

(4) save the packed file NEWTH.TMP by copying it somewhere;

(5) delete all files whose names end with .TMP.

(6) Now examine the printed output OUTPUT., and send it to the printer, delete it, or save it.

The logical unit numbers for the files are the same on all versions of DOE-2; INPUT.TMP is 5, OUTPUT. is 6, NEWTH.TMP is 1, WEATHR.TMP is 10, and STOUT.TMP (a scratch file) is 17.

Execution of the listing and/or statistical summary functions **without** packing uses virtually the same procedure. The hourly input weather data file, whether packed or raw, is copied to WEATHR.TMP. The user's input again goes on INPUT.TMP. The program is executed and OUTPUT. is examined. There will be no NEWTH.TMP, since no packing was performed.

TMY Caveats

The Detroit TMY file has bad and/or zero barometric pressure data in the months of May and December. This causes the DOE-2 weather processor to abort.

The Phoenix TMY has bad data for diffuse solar during hour 20 of May 28. This number should be set to zero, by using your local editor, on the raw data file.

The Caribou, Maine, TMY has anomalous temperature rise in hour 23 on January 28. This should be corrected with the editor.

DOE-2.1 WEATHER UTILITY PROGRAM

-- Statistical Summary --

TMY NASHVILLE, TN MONTHLY WEATHER DATA SUMMARY DOE-2.1

LATITUDE = 36.10 LONGITUDE = 86.70 TIME ZONE = 6

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
AVG. TEMP. (F) (DRYBULB)	40.1	42.2	49.3	58.5	67.6	75.1	78.3	76.9	71.4	60.3	50.7	40.5	59.3
AVG. TEMP. (F) (WETBULB)	37.0	38.1	43.7	51.5	60.7	67.0	71.4	69.9	65.1	54.1	45.3	36.5	53.4
AVG. DAILY MAX. TEMP.	48.7	52.3	59.2	69.4	77.6	85.0	87.6	87.0	81.8	70.5	59.8	48.3	69.0
AVG. DAILY MIN. TEMP.	31.4	31.6	38.2	46.1	56.6	64.4	69.4	68.1	61.1	50.0	41.9	32.3	49.4
HEATING DEG. DAYS (BASE 65)	773.5	645.5	506.0	247.0	66.0	1.5	.0	.0	16.5	209.0	426.5	765.0	3656.5
(BASE 60)	618.5	505.5	359.0	140.0	30.5	.0	.0	.0	1.0	120.0	297.0	617.0	2688.5
(BASE 55)	467.5	373.5	231.0	67.5	10.5	.0	.0	.0	.0	56.0	183.5	474.0	1863.5
(BASE 50)	329.0	265.0	123.5	19.0	2.5	.0	.0	.0	.0	13.0	104.0	340.5	1196.5
COOLING DEG. DAYS (BASE 80)	.0	.0	.0	.0	.0	4.0	12.0	15.0	1.0	.0	.0	.0	32.0
(BASE 75)	.0	.0	.0	.0	9.0	50.5	122.5	96.5	32.0	1.5	.0	.0	312.0
(BASE 70)	.0	.0	.0	5.0	44.5	154.0	266.5	235.0	95.5	21.5	.0	.0	822.0
(BASE 65)	.0	.0	.0	29.0	131.0	292.5	418.5	390.0	209.0	62.5	2.0	.0	1534.5
HEATING DEG. HRS./24 (BASE 65)	770.5	641.9	497.8	257.4	91.4	12.6	2.3	3.7	39.3	225.9	439.9	759.9	3742.5
(BASE 60)	616.3	511.8	366.9	168.8	46.5	3.7	.0	.3	13.7	142.2	320.3	613.2	2803.6
(BASE 55)	472.8	391.9	253.4	102.7	22.6	.4	.0	.0	3.2	76.8	217.5	477.1	2018.3
(BASE 50)	347.6	284.6	159.2	54.8	10.9	.0	.0	.0	.1	34.5	132.7	350.3	1374.6
COOLING DEG. HRS./24 (BASE 80)	.0	.0	.0	.8	11.5	44.0	70.8	53.3	27.5	3.6	.0	.0	211.6
(BASE 75)	.0	.0	.0	8.6	40.8	104.6	150.9	124.0	66.1	15.0	.0	.0	510.0
(BASE 70)	.0	.1	.8	27.2	91.9	195.3	266.3	232.6	132.3	38.0	.7	.0	985.4
(BASE 65)	.0	3.8	10.1	61.8	171.7	316.5	413.2	372.2	230.9	80.1	10.9	1.0	1672.3
MAXIMUM TEMP.	62	72	73	83	88	95	93	95	92	87	73	68	95
MINIMUM TEMP.	11	14	22	33	35	53	60	58	49	33	24	8	8
NO. DAYS MAX. 90 AND ABOVE	0	0	0	0	0	4	13	9	5	0	0	0	31
NO. DAYS MAX. 32 AND BELOW	2	2	0	0	0	0	0	0	0	0	0	2	6
NO. DAYS MIN. 32 AND BELOW	18	19	8	0	0	0	0	0	0	0	5	17	67
NO. DAYS MIN. 0 AND BELOW	0	0	0	0	0	0	0	0	0	0	0	0	0
AVG. WIND SPEED (MPH)	9.1	8.8	11.5	10.8	8.2	7.2	7.0	6.3	5.8	7.9	9.9	9.7	8.5
AVG. WIND SPEED (DAY)	10.0	9.8	12.8	12.0	9.4	8.3	7.8	7.3	7.1	9.0	10.6	10.2	9.4
AVG. WIND SPEED (NIGHT)	8.5	8.0	10.3	9.2	6.4	5.5	5.8	5.0	4.3	6.9	9.2	9.3	7.5
AVG. TEMP. (DAY)	42.7	45.6	52.5	62.7	71.1	79.0	81.6	80.8	75.6	64.8	54.2	43.4	64.6
AVG. TEMP. (NIGHT)	38.3	39.5	46.1	53.1	62.3	69.1	73.3	71.8	66.6	55.8	47.7	38.3	53.7
AVG. SKY COVER (DAY)	6.6	6.8	5.6	4.7	5.0	4.2	4.5	3.0	4.9	4.5	5.9	6.7	5.1
AVG. REL. HUM. AT 4AM	82.3	81.6	78.4	82.7	89.3	86.0	92.4	91.0	90.1	83.2	76.3	75.4	84.1
10AM	75.7	70.2	61.1	57.7	63.0	60.6	67.5	64.2	67.7	64.4	68.1	70.6	65.9
4PM	68.2	57.7	54.0	49.7	52.0	51.1	58.3	55.6	55.4	52.5	56.8	60.8	56.0
10PM	79.8	73.0	68.1	73.5	75.9	75.3	78.4	81.2	82.0	75.2	69.7	71.7	75.3

TMY NASHVILLE, TN MONTHLY WEATHER DATA SUMMARY DOE-2.1

LATITUDE = 36.10 LONGITUDE = 86.70 TIME ZONE = 6

Btu/Ft²

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
AVG. DAILY DIRECT NORMAL SOLAR	685.9	840.1	1051.1	1219.2	1321.3	1606.4	1380.9	1340.6	1376.2	1133.7	804.6	686.2	1121.4
AVG. DAILY TOTAL HORIZNTL SOLAR	553.0	808.7	1179.7	1560.8	1719.4	2031.6	1918.3	1758.1	1417.9	1062.3	691.0	509.6	1269.6
MAX. DAILY DIRECT NORMAL SOLAR	2226.0	2541.0	2652.0	2410.0	3095.0	3121.0	2232.0	2380.0	2699.0	2214.0	2358.0	1785.0	3121.0
MAX. DAILY TOTAL HORIZNTL SOLAR	1153.0	1541.0	2001.0	2202.0	2595.0	2568.0	2397.0	2326.0	2067.0	1516.0	1334.0	966.0	2595.0
MIN. DAILY DIRECT NORMAL SOLAR	.0	1.0	.0	4.0	.0	243.0	154.0	427.0	.0	1.0	.0	.0	.0
MIN. DAILY TOTAL HORIZNTL SOLAR	73.0	117.0	244.0	331.0	391.0	1111.0	983.0	1108.0	205.0	189.0	100.0	59.0	59.0
MAX. HRLY DIRECT NORMAL SOLAR	295.0	303.0	306.0	314.0	309.0	282.0	260.0	306.0	287.0	310.0	321.0	312.0	321.0
MAX. HRLY TOTAL HORIZNTL SOLAR	187.0	230.0	278.0	311.0	327.0	314.0	295.0	318.0	282.0	239.0	215.0	194.0	327.0
AVG. MAX. HRLY DIRECT NORML SOLAR	136.1	161.2	166.7	202.6	203.2	224.0	188.7	221.8	192.1	198.3	158.3	140.0	182.8
AVG. MAX. HRLY TOTAL HRZNTL SOLAR	102.1	145.3	186.5	239.4	248.0	275.9	243.9	265.3	206.8	179.4	129.0	99.6	193.6

Btu/Ft²-hr

AVG. DAILY TOTAL VERTICAL SOLAR (Btu/Ft²)

AZIMUTH													
N	168.1	248.9	352.7	476.4	530.0	686.4	669.0	536.9	383.6	300.2	205.4	149.3	392.9
E	353.7	551.9	699.5	922.4	980.9	1162.3	1132.9	1037.0	872.2	640.1	414.7	331.4	759.0
S	828.7	969.7	1046.8	1029.7	875.8	887.0	921.1	1036.0	1107.1	1181.9	962.8	812.2	971.3
W	357.9	491.5	765.5	915.0	974.2	1176.1	1163.8	977.7	853.7	671.0	424.8	313.2	758.3

MAX. DAILY TOTAL VERTICAL SOLAR (Btu/Ft²)

AZIMUTH													
N	286.6	380.7	506.8	724.9	740.5	853.0	824.1	726.1	575.0	479.0	296.6	241.8	853.0
E	747.3	1077.5	1142.1	1364.0	1346.4	1677.5	1408.7	1304.2	1282.1	954.4	970.1	751.8	1677.5
S	1796.9	1875.0	1707.1	1426.1	1233.4	1066.5	1174.4	1317.1	1588.0	1713.2	1901.3	1695.9	1901.3
W	696.6	955.9	1285.9	1352.2	1367.3	1483.4	1449.5	1290.3	1233.1	902.7	762.1	658.7	1483.4

MAX. HRLY TOTAL VERTICAL SOLAR (Btu/Ft²-hr)

AZIMUTH													
N	49.0	72.4	83.2	91.0	97.9	100.8	96.7	90.3	85.3	72.1	45.6	45.3	100.8
E	193.4	246.1	239.1	238.5	285.3	258.2	230.9	230.4	236.7	209.8	228.6	208.9	285.3
S	266.6	262.3	240.9	206.5	173.7	163.5	163.3	192.9	226.4	267.8	281.0	319.1	319.1
W	176.9	217.7	249.7	244.0	251.2	243.2	239.9	223.5	235.4	213.7	208.7	172.3	251.2

TMY NASHVILLE, TN MONTHLY WEATHER DATA SUMMARY DOE-2.1

DESIGN TEMPERATURES ---------- SUMMER ---------- WINTER

PER CENT	T(DRY)	T(WET)	T(DRY)
1.Ø	91	77	14
2.5	9Ø	77	19
5.Ø	89	76	

MONTHLY AVERAGE TEMPERATURES AS A FUNCTION OF HOUR OF THE DAY

HOUR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Ø	38.6	38.6	45.Ø	52.2	6Ø.5	67.4	71.9	7Ø.5	65.6	54.8	47.2	37.5	54.2
1	37.7	37.6	43.9	51.5	59.5	66.5	71.Ø	69.9	64.6	54.4	46.4	36.9	53.4
2	36.7	37.1	43.3	51.Ø	58.8	65.6	7Ø.1	69.2	64.Ø	53.9	45.8	36.1	52.7
3	35.8	36.7	42.6	5Ø.8	58.2	66.2	7Ø.1	69.Ø	63.3	53.5	45.5	35.8	52.4
4	34.8	36.2	41.9	5Ø.7	58.Ø	66.9	7Ø.1	68.8	63.Ø	53.1	45.6	35.5	52.1
5	34.9	35.9	41.5	5Ø.2	59.3	67.5	7Ø.1	68.6	62.7	52.6	45.3	35.Ø	52.Ø
6	35.Ø	35.8	42.3	53.5	62.2	7Ø.9	73.5	72.1	64.8	55.4	47.Ø	36.3	54.2
7	36.7	37.5	44.6	57.Ø	65.4	74.2	76.9	75.2	68.4	58.Ø	48.5	37.5	56.8
8	38.6	41.Ø	47.6	6Ø.3	68.4	77.6	8Ø.3	78.7	71.8	6Ø.8	5Ø.1	38.6	59.6
9	4Ø.8	43.5	5Ø.5	62.3	7Ø.5	79.5	82.Ø	8Ø.7	74.5	63.3	52.4	41.Ø	61.8
1Ø	42.4	45.9	52.5	64.5	72.6	81.3	83.8	82.8	76.9	65.5	54.6	43.2	63.9
11	43.7	47.5	54.1	66.5	74.4	83.2	85.5	84.9	78.5	67.9	56.8	45.5	65.8
12	45.Ø	48.8	55.7	67.1	75.Ø	83.7	85.8	85.3	79.7	68.7	57.4	45.9	66.6
13	45.8	49.4	57.1	67.6	76.Ø	84.2	85.7	85.6	8Ø.7	69.6	57.9	46.5	67.3
14	45.9	49.2	57.8	68.2	76.5	84.8	86.Ø	86.Ø	81.Ø	7Ø.4	58.5	46.9	67.7
15	45.3	48.5	57.9	66.6	76.9	83.4	85.3	84.5	8Ø.6	68.1	56.6	45.7	66.7
16	43.6	47.6	56.8	65.1	76.Ø	82.2	84.6	83.2	79.5	65.9	54.7	44.5	65.4
17	42.2	45.9	54.6	63.4	74.5	8Ø.8	84.Ø	81.6	76.5	63.5	52.9	43.2	63.7
18	41.4	44.1	51.7	6Ø.8	71.3	78.2	81.7	79.4	73.5	61.7	51.6	42.3	61.6
19	4Ø.9	43.Ø	5Ø.2	58.3	69.Ø	75.6	79.5	77.1	71.6	59.8	5Ø.2	41.3	59.8
2Ø	4Ø.1	42.1	49.Ø	55.7	66.9	73.1	77.4	74.8	69.8	58.Ø	48.9	4Ø.3	58.1
21	39.8	41.2	48.2	54.6	65.6	71.6	75.8	73.6	68.5	57.Ø	48.3	39.7	57.1
22	39.1	4Ø.3	47.2	53.5	64.1	7Ø.2	74.3	72.4	67.4	56.1	47.7	39.1	56.Ø
23	38.5	39.8	46.5	52.2	62.7	68.7	72.7	71.1	66.4	55.1	47.Ø	38.1	55.Ø

GROUND TEMPERATURES	512.2	5Ø9.3	5Ø9.Ø	51Ø.4	516.Ø	521.5	526.3	529.3	529.6	527.1	522.4	517.1
CLEARNESS NUMBERS	1.ØØ	1.ØØ	1.ØØ	1.ØØ	1.ØØ	1.ØØ	1.ØØ	1.ØØ	1.ØØ	1.ØØ	1.ØØ	1.ØØ

ONE NEW BUG — D-44

Following is the description of a new bug discovered in DOE-2.1C. Users are urged to document suspected bugs and report them to us. Below is the bug description, its temporary (no code change) solution, and the date the permanent correction was moved to our 2.1C release files. If you received a tape sent by us after the date given in the bug description, then the bug fix is already on your tape in one of the "mod" files. In any case, before you fix a bug, make sure it has not already been corrected on your DOE-2.1C tape. After the bug description is the bug fix in the form of UPDATE modification directives. Bug fixes are independent of each other (they do not interact); thus, you can fix only those bugs you consider important. Lines beginning with */ are UPDATE comment lines and can be left out.

Questions or comments about bugs should be directed (in writing) to Fred Buhl, Simulation Research Group, 90-3147, Lawrence Berkeley Laboratory, Berkeley, Ca 94720.

Bug D-44

Constants table is misread when more than one function uses the "table" statement. When more than one function contains "table" statements, only the last function's "table" statement is used. i.e. the PWL(.,.) values computed by other than last function are incorrect.

```
---+----1----+----2----+----3----+----4----+----5----+----6----+----7--

   Example :
       FUNCTION     NAME=FN1    ...
       ASSIGN       TAB1=TABLE  ...
       CALCULATE  ..
       Y1 = PWL( TAB1 , X1 )
       ...
       END
       END-FUNCTION  ..
       FUNCTION     NAME=FN1    ...
       ASSIGN       TAB2=TABLE  ...
       CALCULATE  ..
       Y2 = PWL( TAB2 , X2 )
       ...
       END
       END-FUNCTION  ..

----+----1----+----2----+----3----+----4----+----5----+----6----+----7-
```

will incorrectly calculate Y1 = PWL(TAB2, X1)

Interim solution : declare both table statements in both functions. e.g.

```
---+----1----+----2----+----3----+----4----+----5----+----6----+----7--

        FUNCTION     NAME=FN1    ...
        ASSIGN       TAB1=TABLE  ...
        ASSIGN       TAB2=TABLE  ...
        CALCULATE  ..
        Y1 = PWL( TAB1, X1 )
        ...
        END
        END-FUNCTION  ..
        FUNCTION     NAME=FN1    ...
        ASSIGN       TAB1=TABLE  ...
        ASSIGN       TAB2=TABLE  ...
        CALCULATE  ..
        Y2 = PWL( TAB2, X2 )
        ...
        END
        END-FUNCTION  ..

----+----1----+----2----+----3----+----4----+----5----+----6----+----7-
```

Date moved to release file: 10-13-86

Bug fix mods in file LDS.MOD

```
*/ --- THIS FIXES BUG D-44. 861013.  CONSTANTS TABLE IS MISREAD WHEN
*/ ---     MORE THAN ONE FUNCTION USES THE "TABLE" STATEMENT.
*D FINTL.20
        CALL  MOVEN( IA(MFN+9), ICONT0, 7 )

----+----1----+----2----+----3----+----4----+----5----+----6----+----7--
```

DOE-2 Building Energy Simulation Program — **Version 2.1C**

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