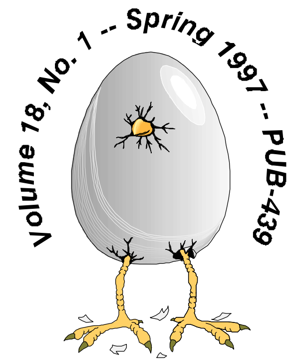
# Building Energy Simulation

# User News

***For Users of DOE-2, SPARK, BLAST and their Derivatives***


## *What's New?*

❅ ***User News* on the WWW** The *User News* is at ***http://eande.lbl.gov/BTP/SRG/UNEWS.*** Download the document in PDF format and read it with Adobe's "Acrobat" reader, available free of charge.

❅ **EnergyPro** is a new, Windows-based building energy analysis program from the folks at Gabel-Dodd/EnergySoft. Turn to page 17 for a short description of the program; there will be more information in the next newsletter. In the meantime, check out their website at www.energysoft.com.

❅ **Welcome Aboard!** Paul Bannister of Dunedin, New Zealand is our newest DOE-2 energy consultant. Details on page 23.

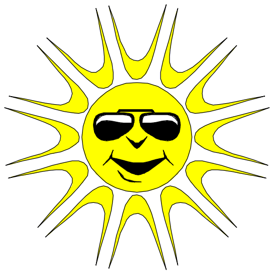
❅ **Changes of address:**
For **DOE-Plus** (page 18): Steve Byrne, ITEM Systems, 321 High School Road NE, #344, Bainbridge Island, WA 98110. For the **German resource center** (page 24): Ingenieurbüro Barath & Wagner GmbH, Postfach 20 21 41, D-41552 Kaarst, Germany.

❅ **Free DOE-2 Help** Call or fax our modeling expert, Bruce Birdsall, for questions about DOE-2. This service is supported by LBNL's Simulation Research Group. Phone Bruce at (510) 829-8459 between the hours of 10 a.m. and 3 p.m. PDT.

## *What's Inside?*




The *User News* is published by the Simulation Research Group at LBNL with cooperation from the BLAST Support Office at the University of Illinois. Direct comments or submissions to Kathy Ellington, Editor, MS: 90-3147, Lawrence Berkeley National Laboratory, Berkeley, CA 94720, or email kathy@gundog.lbl.gov or fax us at (510) 486-4089. Direct BLAST-related inquiries to the BLAST Support Office, phone (217) 333-3977 or email support@blast.bso.uiuc.edu ☺☺☺ 04/97 2000 © 1997 Regents of the University of California, Lawrence Berkeley National Laboratory. This work was supported by the Assistant Secretary for Energy Efficiency and Renewable Energy, Office of Building Technology, State and Community Programs, Office of Building Systems of the U.S. Dept. of Energy, under Contract No. DE-AC03-76SF00098. Energy and Environment Division, Lawrence Berkeley National Laboratory, University of California, Berkeley, California 94720 USA



# Does It Matter Which Weather Data You Use in Energy Simulations? [1]

By
Drury B. Crawley, U.S. Department of Energy
and
Y. Joe Huang, Lawrence Berkeley National Laboratory

## Synopsis

Users of energy simulation programs often have a wide variety of weather data from which to choose—from locally recorded, measured data to *typical* data sets. Using a prototype building, the influence of locally measured weather data and typical weather data sets on annual energy consumption, demand, and costs are compared.

## Abstract

Users of energy simulation programs often have a variety of weather data from which to choose–from locally recorded, measured weather data to pre-selected 'typical' years–a bewildering range of options. In the last two years, several organizations have developed new typical weather data sets: WYEC2, TMY2, CWEC, and CTZ2. Unfortunately, neither how these new data influence energy simulation results nor how they compare to existing typical data sets or actual weather data is well documented.

In this paper, we present results from the DOE-2.1E hourly energy simulation program for a prototype office building as influenced by local measured weather data for multiple years and several weather data sets for a set of North American locations. We compare the influence of the various weather data sets on simulated annual energy use and energy costs. Statistics for temperature, solar radiation, and heating and cooling degree days for the different locations and data sets are also presented. Where possible, we explain the variation relative to the different designs used in developing each data set. We also show the variation inherent in actual weather data and how it influences simulation results. Finally, based on these results, we answer the question—does it really matter which weather data you use?

## Introduction

The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), National Renewable Energy Laboratory (NREL), WATSUN Simulation Laboratory, and California Energy Commission (CEC) have all recently released updated typical weather data sets to use for simulating building energy performance: WYEC2, TMY2, CWEC, and CTZ2, respectively. Each designed their data sets to meet a particular need. ASHRAE designed the WYEC2 data set to represent typical weather patterns. NREL updated the TMY2 data sets to represent the most recent period of record available for work that requires insolation data. WATSUN Simulation Laboratory created the CWEC weather data sets for use by the National Research Council Canada in developing and complying with their new National Energy Code for Buildings. The CEC wanted to update their CTZ weather data for California Title 24 energy standards, as well as make them more representative of` average conditions within each climate region. All groups intended their weather data sets to be usable with energy simulation programs. A recent study [HAB 95] compared measured weather data in calibrated DOE-2

[1] Presented at the ACEEE 1996 Summer Study on Energy Efficiency in Buildings, 25-31 August 1996, Asilomar Conference Center, Pacific Grove, California.

simulations versus TMY data. The four weather data sets (WYEC2, TMY2, CWEC, and CTZ2) were each developed with controlled methodologies; a specific method was used to determine which data from the actual weather data period of record would be used. These methods did not include evaluating the impact that the new data might have on energy simulation results nor how the data sets compare to actual weather data or other existing typical data sets. In this paper, we demonstrate these impacts for the TMY2 and WYEC2 data sets: comparison with actual weather data and energy simulation results.

## Weather Data Sets

Over the past 20 years, several groups have developed weather data sets specifically designed for use in building energy simulations. One of the earliest, Test Reference Year (TRY) [NCDC 76], contains dry bulb, wet bulb, and dew point temperatures, wind direction and speed, barometric pressure, relative humidity, cloud cover and type, and a place holder for solar radiation, but no measured solar data. When used in building energy simulations, the simulation program typically estimates the amount of solar radiation based on the cloud cover and cloud type information available for the TRY location. Another weakness of TRY was the method used to select the data. The TRY data are from an actual historic year of weather, selected using a process whereby years in the period of record (~1948-1975) which had months with extremely high or low mean temperatures were progressively eliminated until only one year remained. This tended to result in a particularly mild year that, either by intention or default, excluded typical extreme conditions. TRY data are available for 60 locations in the U.S.

To deal with the limitations of TRY, particularly the lack of solar data, the National Climatic Data Center (NCDC) together with Sandia National Laboratory created a new data set, Typical Meteorological Year (TMY). TMY includes, in addition to the data contained in TRY, total horizontal and direct normal insolation data for 234 U.S. locations [NCDC 1981]. These solar data were measured for 26 of the locations and estimated from cloud cover and type for the other 208 locations. Data in this set consist of 12 months selected from an approximately 23-year period of record (~1952-1975—available data varied by location) to represent typical months. The method used is similar to that used for the TRY but is based on individual months rather than entire years. The TMY months were selected based on a monthly composite weighting of solar radiation, dry bulb temperature, dew point temperature, and wind velocity as compared to the long term distribution of those values. Months that were closest to the long term distribution were selected. Each resulting TMY data file contains months from different years.

In the late 1970s, the CEC developed a data set specifically for use in complying with the new Title 24 building energy regulations. They mapped the climate regions of the state, dividing it into 16 regions. Then they created a weather data set—California Thermal Zones (CTZ)—with a weather file for each region. The CTZ are based on the TMY format and several of the CTZ files were derived from a specific TMY location. In 1992, the CEC updated their CTZ data set, creating CTZ2 [CAL 1992], with data in ASHRAE's new WYEC2 format. In addition, the temperature profiles from the original CTZ data set were adjusted to make their monthly means correspond to the average monthly means of all the locations within each climate zone. More recently, the CEC developed a method to adjust the CTZ2 weather files to a specific location [CAL 1994]. Essentially, CEC modified the existing CTZ2 weather file to match another city's specific weather design day conditions [ASH 93].

In 1980, ASHRAE initiated a research project [CROW 80] to investigate whether weather data could be assembled to represent more typical weather patterns than either a single representative year or an assemblage of months. This weather data set—known as Weather Year for Energy Calculations (WYEC) [ASH 85]—uses the TRY format and includes solar data (measured where available, otherwise calculated based on cloud cover and type). After the test case proved successful, ASHRAE commissioned development for an additional 50 locations for North America, which were completed in late 1983 [CROW 83]. In total, data for 51 North American locations were created (46 locations in the United States and 5 in Canada). More recently, ASHRAE sponsored research to update insolation models [PER 92] and updated the WYEC data set. The TMY format was used as the starting point and extended to include illumination data. The new format is known as WYEC2, for WYEC version 2.

In 1993, NREL created a new long-term insolation data set based on the 1961-1990 period of record known as the National Solar Radiation Data Base (NSRDB). In conjunction with the National Climatic Data Center (NCDC), they published a combined set of weather and solar data for 1961-1990. These data are known as Solar and Meteorological Surface Observational Network (SAMSON) [NCDC 93] and include 30 years of data for 239 locations—most of those in the original TMY data set. As with the TMY data set, only 56 locations have measured solar data for at least a portion of the 30-year period of record. For the remaining 183 locations, insolation values were calculated based on the Perez model [PER 92]. After completing this work, NREL worked with ASHRAE to update the 51 WYEC and 26 primary TMY weather files to create the WYEC2 data set [STO 95]. Separately, NREL updated the TMY data set based on the new period of record (1961-1990) available in SAMSON—creating the TMY2 data set [NREL 95].

In 1992, NRC Canada commissioned the WATSUN Energy Laboratory at the University of Waterloo to create a weather data set for Canadian locations. They used the long term data set developed by the Atmospheric Environment Service, Environment Canada, in a TMY methodology, formatting the resultant data set in ASHRAE's WYEC2 format. To date, data for approximately 40 locations have been created [WAT 92].

In Europe, a data set for European locations (European Test Reference Year) [CEC 95] has been created using a methodology similar to that used by NCDC to derive the TMY. Petrakis [PET 95] recommends procedures for generating Test Meteorological Years from observed data sets.

## Simulation Methodology

For this paper, we simulated an office building using the DOE-2.1E hourly energy simulation program. The building model remained identical for all weather data sets, with HVAC equipment sizing based on design conditions in the ASHRAE *Handbook of Fundamentals* [ASH 93]. The structure used was a 48,000 $ft^2$, three-story office building: a typical, recent, envelope-dominated low-rise U.S. building.
For lighting, efficient 0.8 $W/ft^2$, T-8 fluorescent, 2-lamp, 2 x 4 fixtures with electronic ballasts and occupancy sensors were assumed. Office equipment was assumed at a level of 1.0 $W/ft^2$ for computers, laser printers, photocopiers, and facsimile machines. The building envelope assumed a 40% fenestration-to-wall ratio with glazing varying by location—primarily single-pane, tinted/reflective in southern locations, double-pane, tinted in northern locations. The assumed occupied outside air ventilation rate was 20 CFM/person. The air system simulated was a VAV reheat system with enthalpy-controlled outside air economizer. The central plant included 0.55 kW per ton centrifugal chillers and a 90% efficiency gas-fired boiler. Energy costs were calculated using current local utility rates.

Actual weather data (30-year period of record, 1961-1990) and typical weather data sets (TRY, TMY, TMY2, WYEC, and WYEC2) were used in the simulations. Five U.S. locations were selected in order to cover a range of typical climatic patterns: Los Angeles, Miami, Minneapolis, Seattle, and Washington, D. C. The maximum, average, median, and minimum of the 1961-1990 weather data for temperature, solar radiation, and heating and cooling degree days for the different locations along with the 99%

(winter) and 2.5% (summer) design temperature values [ASH 93] are shown in Table 2. Similar statistics for typical weather data sets are also shown in Table 2. In the tables and the figures, WYEC2 (TMY) means WYEC2 data derived from original TMY.

### Results

In Figures 1 through 5 the office building simulation results, using 30 years of actual weather data (1961-1990), are shown in terms of end-use energy performance and energy costs by fuel type for the five locations. As shown in the figures, locations that are heating-dominated (Minneapolis) or have a more balanced amount of heating and cooling (Seattle and Washington, D.C.) demonstrate a higher variation in energy use. Milder or cooling-dominated climates (Los Angeles and Miami) demonstrate less variation in energy use. Energy cost variations are somewhat dampened since monthly peak demands play an important part—not just normal hourly weather.

Table 1 summarizes the variability seen in Figures 1-5 (30 years of actual weather data). For each location, the average value, along with minimum and maximum percent change from that value, are shown for annual energy consumption, peak annual electrical demand, and annual energy costs.

Figures 6-10 compare the weather data sets results in terms of end-use energy performance and energy costs by fuel type for the five locations. Also shown are the maximum, average, and minimum for the simulations using the actual weather data for the 30-year period of record (Figures 1-5).

### Summary and Conclusions

The range of energy consumption due to actual weather variation can be significant—as much as +7.0%/-11.0% from long-term average weather patterns for these five locations. The average variation in annual energy consumption due to weather variation is ±5%. Annual variation in weather mostly affects energy consumption in heating-dominated locations such as Minneapolis. Annual weather variations have the least impact on energy consumption in cooling-dominated locations such as Los Angeles and Miami. Where heating and cooling loads are more balanced, as in Seattle and Washington, the impact is more variable. The variation in energy consumption is similar to that reported [HAB 95] for measured and TMY weather data; results showed that the energy consumption values predicted by DOE-2 were consistently higher by 5 to 15% than the measured energy consumption.

As shown in Table 1, the range of peak electrical demand variation due to actual weather patterns is also significant—as much as +9.6%/-9.7% for these five locations. Variation in peak demand on average is ±6%—larger than that for energy consumption. Similar to energy consumption, the least variation is apparent in Miami, a cooling-dominated location. Unlike energy consumption, peak demand varies considerably more in Los Angeles, a location with relatively mild but variable weather conditions. Similar to Los Angeles, Seattle has higher variation in electric demand. Because the simulated building is gas-heated, electrical demand variation is less than that of energy consumption in heating-dominated climates such as Minneapolis. For Washington, peak electrical demand variability is somewhat less for than energy consumption.

Annual energy cost variations due to weather variation are significant but not as large as for energy consumption—as much as +3.6%/-4.4% from long-term average weather pattern for these five locations.

Variation in annual energy cost due to weather variation is on average ±3%. Similar to energy consumption, locations that are heating-dominated (Minneapolis) have greater variation than do locations that are more balanced in heating and cooling loads (Seattle and Washington) or that are cooling-dominated (Los Angeles and Miami). Since annual peak electrical demand charges are more constant, total electricity costs (and total energy costs) vary less overall than energy consumption or peak electrical demand.

The TRY data set varies the most from the average of the 30-year actual weather results. This is probably because each location has a specific year of data—no one year can represent the long-term typical weather patterns. In Figures 6-10, the results for the TRY data sets often vary the most from the average—higher and lower (except in more solar-dominated Los Angeles and Miami—solar data in the TRY case was estimated by DOE-2). In one case (Minneapolis) the annual energy costs for the TRY exceed the maximum for the 30-year actual weather data set.

As shown in Table 2, the TMY2/TMY data sets more closely match the 30-year actual weather solar insolation statistics and the WYEC2/WYEC data sets more closely match the design temperatures and degree days. In no cases do either the TMY2/TMY or WYEC2/WYEC perform consistently better. Either the design temperatures or the insolation vary significantly from the long-term average. There is also significant variation from the design temperatures for each location, some of which is attributable to the new period of record (1961-1990) for the TMY2 data and the 30-year actual weather data versus the older period of record (~1948-1975) for most of the other data sets (TRY, WYEC, WYEC2, and ASHRAE design temperatures). None of the methods for selecting typical weather data is consistently better than the others.

## Recommendations

Users of energy simulation programs should avoid using TRY-type weather data. A more comprehensive method such as used for the TMY2 and WYEC2 data sets are more appropriate and will result in predicted energy consumption and energy costs that are closer to the long-term average. Newer data sets (TMY2 and WYEC2) should be used instead of the older TRY, TMY, or WYEC, as the newer data sets are based on improved solar models and more closely match the long-term average climatic conditions.

Since TMY2 data provide insolation that is closer to the long-term average than the other available data sets, TMY2 should be used in building energy simulations where insolation is critical to the results (for example in buildings that are daylit, have large window/wall ratios, or are poorly insulated). WYEC2 provides a closer match to long-term temperature patterns and should be used where those are important to building energy simulations.

The authors also have several recommendations for development of future weather data sets. The TMY2/TMY method appears to work well in most cases but the resultant files may need to be adjusted to match the long-term average statistics more closely—the mean of the 30-year period of record in this case. A second approach would be to create a typical weather file that has three years: typical (average), cold/cloudy, and hot/sunny. This would capture more than the average conditions and provide simulation results that identify some of the uncertainty and variability inherent in weather. Last, the method used in this paper needs to be attempted on a broader scale—more typical weather data sets and actual weather data. Also, it should be attempted with at least a residential-scale building and a smaller commercial building (<10,000 $ft^2$).

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**Figure 1**

**Effect of Actual Weather Variation on Energy Consumption / Energy Costs in Los Angeles, CA**

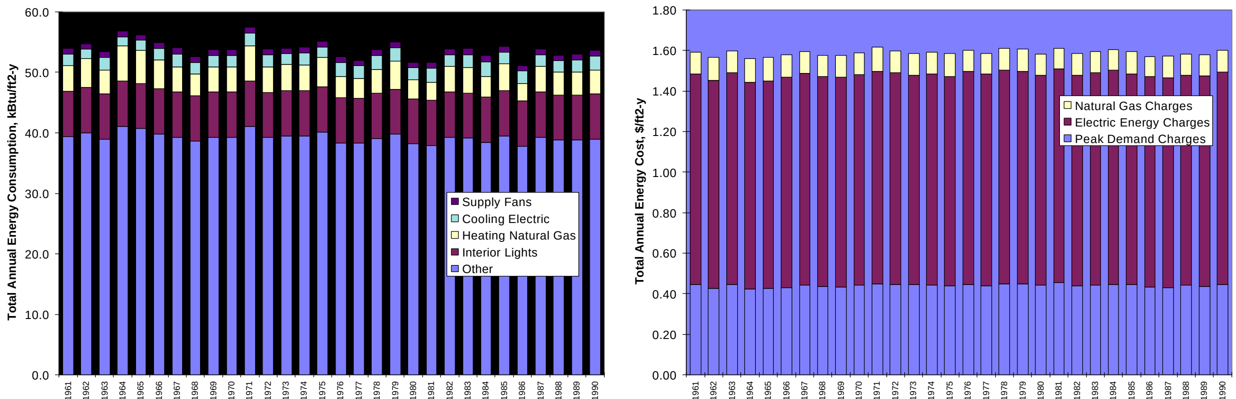
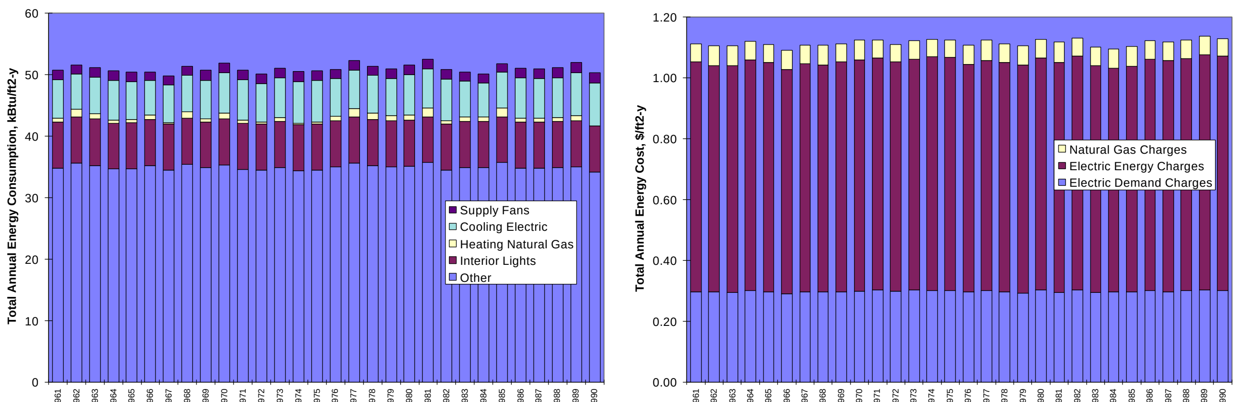
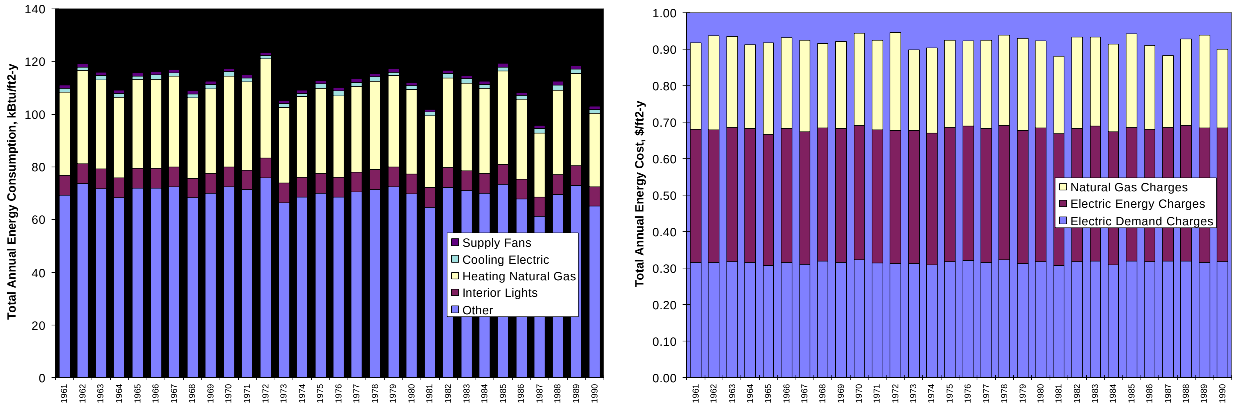



**Figure 2**

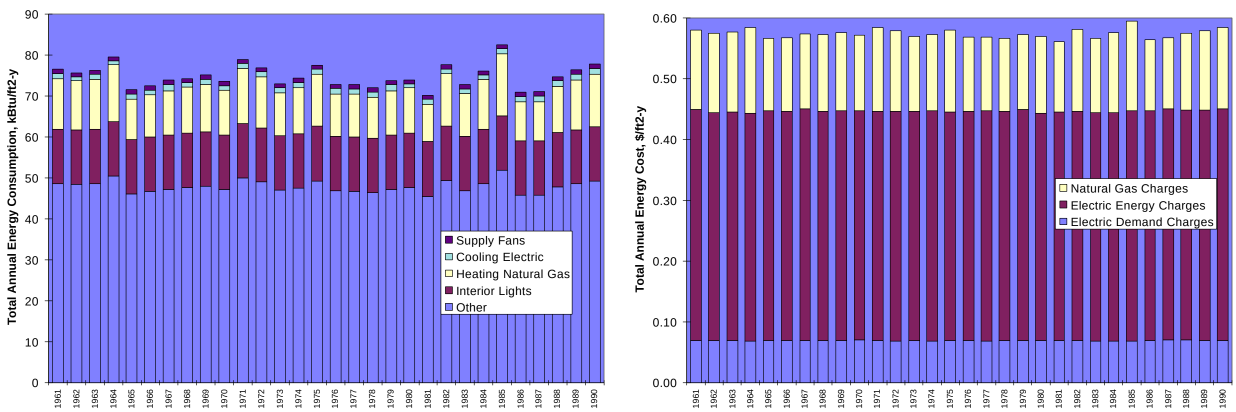
**Effect of Actual Weather Variation on Energy Consumption / Energy Costs in Miami, FL**



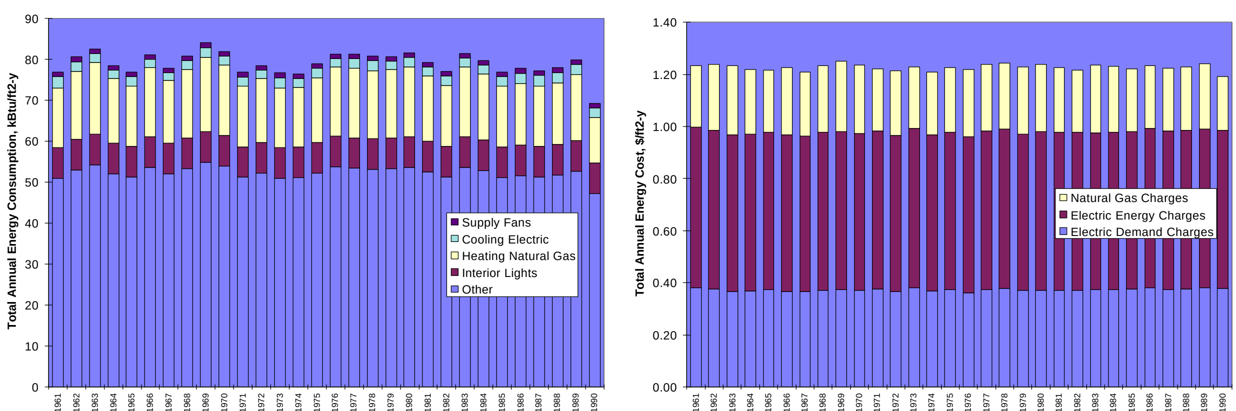
## Figure 3
### Effect of Actual Weather Variation on Energy Consumption / Energy Costs in Minneapolis, MN



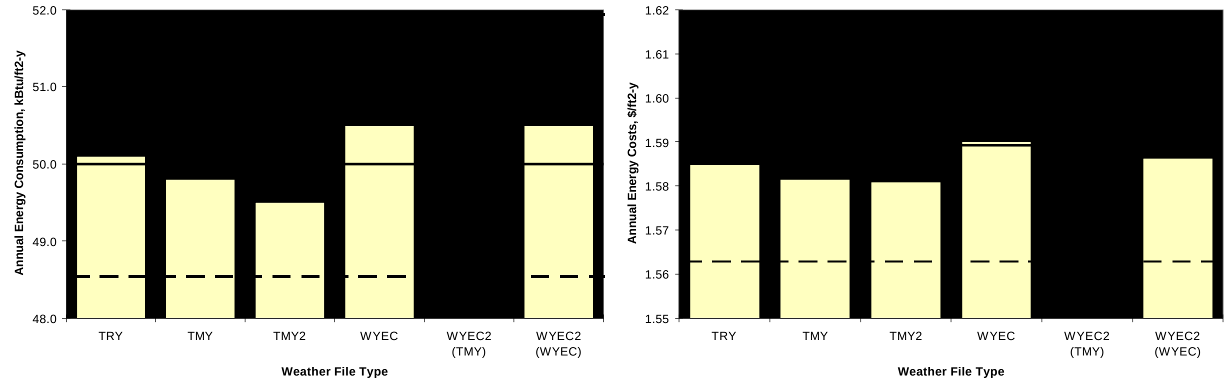

## Figure 4
### Effect of Actual Weather Variation on Energy Consumption / Energy Costs in Seattle, WA



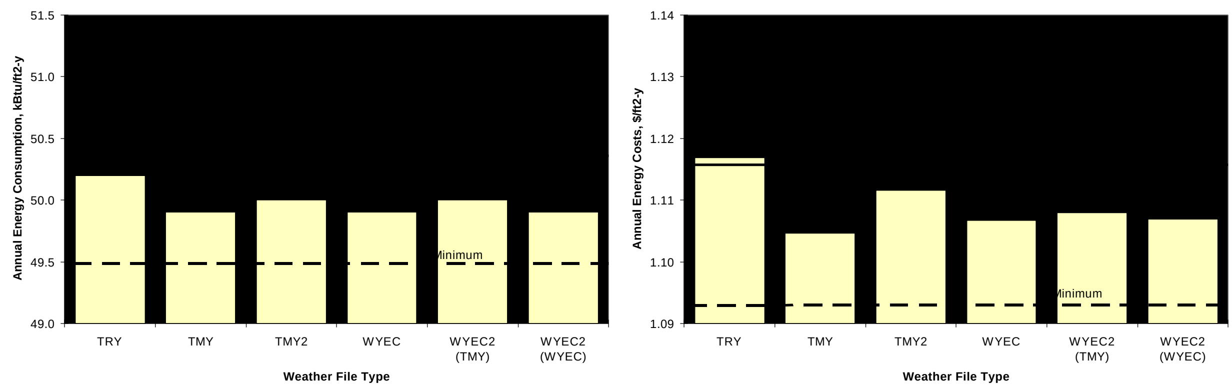

## Figure 5
### Effect of Actual Weather Variation on Energy Consumption / Energy Costs in Washington, D. C.



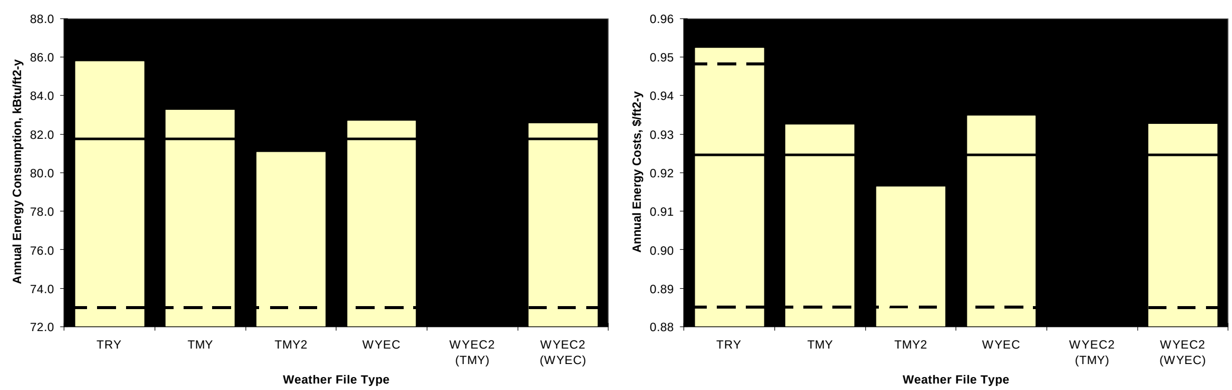
## Figure 6
## Comparison of Simulation Results in Los Angeles, CA. For Weather File Types and Actual Weather



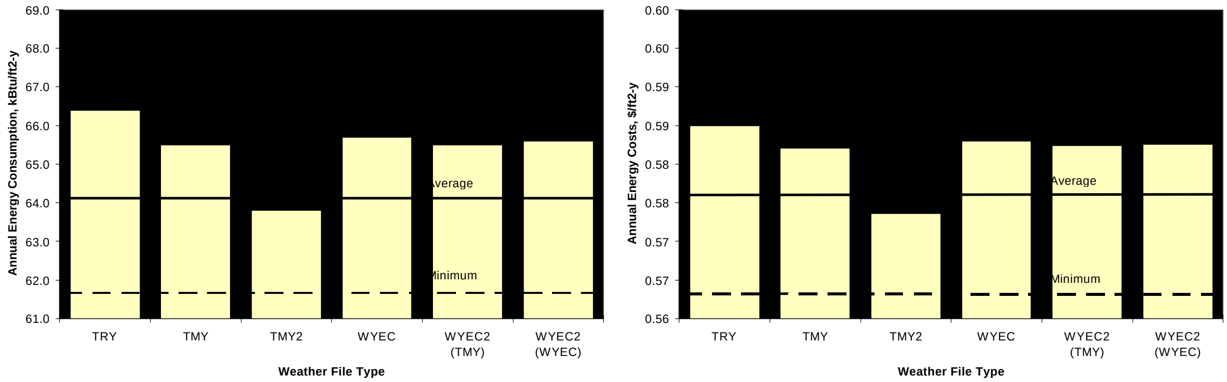

## Figure 7
## Comparison of Simulation Results in Miami, FL, for Weather File Types and Actual Weather



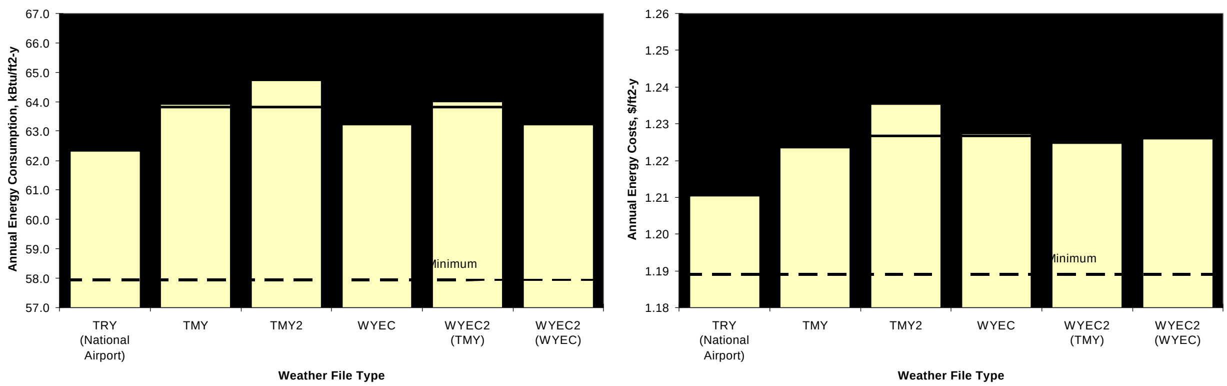

## Figure 8
## Comparison of Simulation Results in Minneapolis, MN, for Weather File Types and Actual Weather



## Figure 9
**Comparison of Simulation Results in Seattle, WA, for Weather File Types and Actual Weather**




## Figure 10
**Comparison of Simulation Results in Washington, DC for Weather File Types and Actual Weather**




## Table 1
**Comparison of Variation in Energy Consumption, Demand, and Costs Due to Weather Variation**

| Location | **Average** (Min/Max -/+%) | | |
|---|---|---|---|
| | **Total Annual Energy Consumption, kBtu/ft$^2$-y** | **Annual Peak Electric Demand, kW** | **Total Annual Energy Costs, \$/ft$^2$-y** |
| **Los Angeles, California** | **49.9** (-3.0%/4.0%) | **197.0** (-9.1%/9.6%) | **1.59** (-1.7%/1.7%) |
| **Miami, Florida** | **50.3** (-1.8%/1.8%) | **224.9** (-2.5%/2.3%) | **1.11** (-2.1%/1.9%) |
| **Minneapolis, Minnesota** | **81.4** (-11.0%/7.0%) | **210.9** (-9.7%/4.4%) | **0.92** (-4.4%/2.6%) |
| **Seattle, Washington** | **63.9** (-3.9%/6.5%) | **215.6** (-6.8%/4.3%) | **0.58** (-2.3%/3.6%) |
| **Washington, D. C.** | **63.8** (-8.1%/4.3%) | **214.4** (-7.9%/3.7%) | **1.23** (-3.0%/2.0%) |

## Table 2
## Comparison of Weather Statistics for 1961-90 Actual Weather and Weather File Types

| Location | Statistic or File Type | | Winter 99% Dry bulb Temperature | Summer 2-1/2% Dry bulb Temperature | Heating Degree Days, 65 F | Cooling Degree Days, 65 F | Direct Normal Solar | Horizontal Solar |
|---|---|---|---|---|---|---|---|---|
| Los Angeles | Design Temperature | | 41 | 80 | | | | |
| California | | Maximum | 47 | 84 | 1915.5 | 933.5 | 1694.8 | 1632.7 |
| | 1961-1990 | Average | 42.6 | 78.8 | 1401.6 | 591.7 | 1532.1 | 1568.1 |
| | | Median | 42 | 78.5 | 1376.3 | 535.5 | 1546.4 | 1564.8 |
| | | Minimum | 39 | 74 | 976.5 | 284.5 | 1365.2 | 1499.7 |
| | TRY | | 42 | 78 | 1518.0 | 391.5 | 1331.5 | 1392.2 |
| | TMY | | 42 | 78 | 1506.5 | 466.5 | 1693.7 | 1611.6 |
| | TMY2 | | 43 | 77 | 1291.0 | 469.5 | 1563.6 | 1579.4 |
| | WYEC | | 41 | 77 | 1704.0 | 459.0 | 1662.6 | 1608.8 |
| | WYEC2 (WYEC) | | 41 | 77 | 1704.0 | 459.0 | 1373.2 | 1553.6 |
| Miami | Design Temperature | | 44 | 90 | | | | |
| Florida | | Maximum | 54 | 92 | 345.0 | 4741.0 | 1453.7 | 1630.9 |
| | 1961-1990 | Average | 44.4 | 89.4 | 190.5 | 4138.7 | 1254.0 | 1532.0 |
| | | Median | 44.5 | 89.0 | 194.8 | 4119.5 | 1274.2 | 1531.5 |
| | | Minimum | 37 | 87 | 17.5 | 3438.0 | 990.8 | 1344.4 |
| | TRY | | 44 | 89 | 147.0 | 4262.5 | 863.7 | 1367.5 |
| | TMY | | 43 | 89 | 188.5 | 4031.0 | 1231.7 | 1482.0 |
| | TMY2 | | 48 | 89 | 141.0 | 4126.5 | 1307.2 | 1557.2 |
| | WYEC2 (TMY) | | 43 | 89 | 188.5 | 4032.5 | 1071.0 | 1477.5 |
| | WYEC | | 42 | 89 | 227.0 | 4005.0 | 1047.6 | 1478.0 |
| | WYEC2 (WYEC) | | 42 | 89 | 227.0 | 4005.0 | 1049.9 | 1470.2 |
| Minneapolis | Design Temperature | | -16 | 89 | | | | |
| Minnesota | | Maximum | -5 | 95 | 9105.0 | 1124.5 | 1574.6 | 1343.9 |
| | 1961-1990 | Average | -15.7 | 87.9 | 8002.9 | 695.9 | 1265.6 | 1234.0 |
| | | Median | -16.5 | 88.0 | 8077.3 | 688.3 | 1250.4 | 1228.7 |
| | | Minimum | -24 | 84 | 6435.0 | 401.0 | 1041.1 | 1167.2 |
| | TRY | | -25 | 90 | 8345.5 | 911.5 | 1069.0 | 1160.2 |
| | TMY | | -17 | 90 | 8095.0 | 759.5 | 1182.3 | 1169.6 |
| | TMY2 | | -15 | 86 | 7985.5 | 634.0 | 1299.1 | 1257.0 |
| | WYEC | | -20 | 88 | 8070.5 | 750.5 | 1123.3 | 1170.8 |
| | WYEC2 (WYEC) | | -19 | 88 | 8070.0 | 750.5 | 1135.4 | 1161.4 |
| Seattle | Design Temperature | | 21 | 80 | | | | |
| Washington | | Maximum | 31 | 86 | 5674.5 | 338.0 | 1106.6 | 1140.5 |
| | 1961-1990 | Average | 23.7 | 81.5 | 4927.7 | 162.9 | 932.5 | 1055.2 |
| | | Median | 25.5 | 82.0 | 4844.8 | 167.8 | 947.4 | 1056.4 |
| | | Minimum | 13 | 76 | 4338.0 | 52.0 | 664.3 | 1000.1 |
| | TRY | | 27 | 84 | 5373.5 | 142.0 | 675.7 | 933.8 |
| | TMY | | 24 | 81 | 5299.5 | 106.0 | 878.2 | 1031.8 |
| | TMY2 | | 29 | 80 | 4867.0 | 127.0 | 966.4 | 1061.5 |
| | WYEC2 (TMY) | | 24 | 81 | 5295.5 | 106.0 | 878.8 | 1030.8 |
| | WYEC | | 20 | 81 | 5222.5 | 97.0 | 916.5 | 1054.0 |
| | WYEC2 (WYEC) | | 20 | 81 | 5222.5 | 97.0 | 908.1 | 1047.2 |
| Washington, D. C. | Design Temperature | | 14 | 91 | | | | |
| (Dulles Airport) | | Maximum | 18 | 95 | 5538.0 | 1470.0 | 1367.4 | 1402.8 |
| | 1961-1990 | Average | 7.0 | 89.9 | 5017.3 | 1042.4 | 1173.7 | 1303.2 |
| | | Median | 6.5 | 90.0 | 5034.8 | 1019.8 | 1172.3 | 1311.1 |
| | | Minimum | 0 | 87 | 3993.0 | 766.5 | 1020.8 | 1177.4 |
| | TRY (National Airport) | | 13 | 91 | 4112.5 | 1525.5 | 1025.0 | 1231.9 |
| | TMY | | 7 | 90 | 4865.5 | 1054.0 | 1131.2 | 1215.3 |
| | TMY2 | | 8 | 89 | 5233.0 | 1044.0 | 1171.4 | 1300.5 |
| | WYEC2 (TMY) | | 7 | 90 | 4865.5 | 1062.5 | 1023.2 | 1213.5 |
| | WYEC | | 12 | 90 | 4236.0 | 1425.0 | 1000.0 | 1212.3 |
| | WYEC2 (WYEC) | | 12 | 90 | 4236.0 | 1425.0 | 982.6 | 1201.7 |

**I B P S A**

**International Building Performance Simulation Association**

***Fifth International Conference***
***Prague, Czech Republic***
***September 8-10, 1997***

# BUILDING SIMULATION '97

Computer modeling and simulation is a most powerful approach for addressing the complex interactions encountered in buildings and the systems that service them. Modeling and simulation are evolving rapidly, and techniques not feasible just a few years ago are now becoming commonplace. The International Building Performance Simulation Association (IBPSA) was founded in 1986 to advance and promote the science of building performance simulation, with application to the design, construction, operation, and evaluation of new and existing buildings worldwide.

**CONFERENCE THEMES**

- Fundamentals and approaches for building related phenomena, such as heat, moisture, air, fluid and power flow, artificial and day lighting, fire acoustics, indoor air quality and environmental impact.
- Implementation, integration, and quality assurance of modeling and simulation tools.
- Application of modeling and simulation in design of new and refurbished buildings and HVAC systems.
- Integration of modeling and simulation in higher education.
- Use of modeling and simulation in practice.

The conference program will allow for hardware and software demonstrations, and a side-program is envisaged for student presentations of short papers.

**REGISTRATION FEES**

The registration fee includes conference attendance, proceedings, lunches, morning and afternoon refreshments, early-bird reception, welcome reception, and banquet. The accompanying persons registration excludes conference attendance and proceedings.
***IBPSA members will receive a USD 25 discount.***

**VENUE**

Prague is the capital and center of industry, science, and culture of the Czech Republic. Prague is located in the center of Europe and belongs among the best preserved historical cities with unique collections of architectural and cultural monuments. BS '97 will be held at the Czech Technical University in Prague (CTU), situated just north of the center of the city.

**CONFERENCE SECRETARIAT**
***Address all inquiries to:***

**Secretariat Building Simulation '97**
**Faculty of Mechanical Engineering**
**Dept. of Environmental Engineering**
**Czech Technical University in Prague**
**Technicka 4**
**166 07 PRAGUE 6**
**Czech Republic**

**phone/fax +42 2 2345 5616**

**email bs97@fsid.cvut.cz**

**news: http://www.fsid.cvut.cz/bs97**

## Recent Research Newsletter from LBNL's Energy Analysis Program

The latest issue of the *Recent Research* newsletter deals with the impact of energy efficient standards on refrigerators. An important aspect of this comparison is the role of energy test procedures. Two years ago, Japan converted from their own test procedure to the ISO test. As a result, the listed energy use of Japanese refrigerators suddenly jumped 40 percent. The opposite result would probably occur if the United States switched to the ISO test. This example illustrates the key role of energy test procedures. Results from other projects suggest that energy test procedures will soon need drastic overhauling. Almost all appliances, from air conditioners to cars, are now built with microprocessors to control many aspects of their operation. Current test procedures focus on the performance of the hardware characteristics, not the software. The field performance of these appliances may differ sharply from that observed in the laboratory.

Are you trying to figure out how to put your PCs to sleep? A recent LBNL report, "*User Guide to Power Management in PCs and Monitors*", is available at http://eande.lbl.gov/EAP/BEA/LBLReports/39466. The intended audience is computer support staff but you, the energy professional, will certainly want to check it out. This report could easily save you 100 watts!

Alan Meier (akmeier@lbl.gov)



# *"Building Loads Analysis and System Thermodynamics"*

# blastnews

The **Building Loads Analysis and System Thermodynamics (BLAST)** system is a comprehensive set of programs for predicting energy consumption and energy system performance and cost in buildings. The BLAST system was developed by the U.S. Army Construction Engineering Research Laboratory (USACERL) under the sponsorship of the Department of the Air Force, Air Force Engineering and Services Center (AFESC), and the Department of the Army, Office of the Chief of Engineers (OCE). After the original release of BLAST in December 1977, the program was extended and improved under the sponsorship of the General Services Administration, Office of Professional Services; BLAST Version 2.0 was released in June 1979. Under the sponsorship of the Department of the Air Force, Aeronautical System Division, and the Department of Energy, Conservation and Solar Energy Office, the program was further extended; BLAST Version 3.0 was completed in September 1980. Since 1983, the BLAST system has been supported and maintained by the BLAST Support Office at the University of Illinois at Urbana-Champaign.

BLAST can be used to investigate the energy performance of new or retrofit building design options of almost any type and size. In addition to performing peak load (design day) calculations necessary for mechanical equipment design, BLAST also estimates the annual energy performance of the facility, which is essential for the design of solar and total energy (cogeneration) systems and for determining compliance with design energy budgets. Repeated use of BLAST is inexpensive; it can be used to evaluate, modify, and re-evaluate alternate designs on the basis of annual energy consumption and cost.

The BLAST analysis program contains three major subprograms:

- The Space Load Prediction subprogram computes hourly space loads in a building based on weather data and user inputs detailing the building construction and operation.
- The Air Distribution System Simulation subprogram uses the computed space loads, weather data, and user inputs describing the building air- handling system to calculate hot water, steam, gas, chilled water, and electric demands of the building and air-handling system.
- The Central Plant Simulation subprogram uses weather data, results of the air distribution system simulation, and user inputs describing the central plant to simulate boilers, chillers, on-site power generating equipment and solar energy systems; it computes monthly and annual fuel and electrical power consumption.

**BLAST Support Office (BSO)**
**30 Mechanical Engineering Bldg**
**University of Illinois**
**1206 West Green Street**
**Urbana, IL 61801**

**Telephone: ( 217) 333-3977**
**FAX: (217) 244-6534**
**email: support@blast.bso.uiuc.edu**
**http://www.bso.uiuc.edu**

**Heat Balance Loads Calculator (HBLC)**
The BLAST graphical interface (HBLC) is a Windows-based interactive program for producing BLAST input files. HBLC allows the user to visualize the building model as it is developed and modify previously created input files. Within HBLC, each story of the building is represented as a floor plan which may contain several separate zones. Numerous other building details may be investigated and accessed through simple mouse operations. On-line helps provide valuable on-the-spot assistance that will benefit both new and experienced users. HBLC is an excellent tool which will make the process of developing BLAST input files more intuitive and efficient. You can download a demo version of HBLC (for MS Windows) from the BLAST website (User manual included!).
A FREE UPGRADE IS AVAILABLE to registered users, as of July 11. To obtain a password and instructions for downloading, email to: support@blast.bso.uiuc.edu, or call (217) 333-3977. This upgrade may also be obtained by post for a nominal fee.

**WINLCCID 96**
LCCID (Life Cycle Cost in Design) has been a standard in the DoD community since its initial release in 1986. LCCID was developed to perform Life Cycle Cost Analyses (LCCA) for the Department of Defense and their contractors, yet it goes far beyond being just a DoD study tool by providing many features of a general purpose life cycle costing tool. With LCCID, it's easy to carry out "what-if" analyses based on variables such as present and future costs and/or maintenance and repair costs. LCCID allows an analysis based on standard DoD procedures and annually updated escalation factors as well as Energy Conservation Investment Program (ECIP) LCCA. The WinLCCID96 life cycle cost program [See *User News* Vol. 16, No. 4, p. 5]. You can download a demo version of WINLCCID 96 (for MS Windows) from the BLAST website.

**PC BLAST Package**
The standard PC BLAST Package includes the following programs: BLAST, HBLC, BTEXT, WIFE, CHILLER, Report Writer, Report Writer File Generator, Comfort Report program, and the Weather File Reporting Program. A soft copy of the BLAST manual will be included as help files with the software. The Portable BLAST Package does not include HBLC or HBLC source. Executable version of BLAST Software Package for an IBM 386/486/Pentium with a Numeric Co-Processor

| | | |
|---|---|---|
| | 3B386E3-0695 | $950.00 |
| **PORTABLE BLAST (on DOS Formatted Disks)**<br>Source code plus PC Executables and HBLC | 3BPORA3-0695 | $1500.00 |
| **Separate Programs** | **Order Number** | **Price** |
| WINLCCID 96 (initial purchase) | 3LCC3-0396 | $295.00 |
| WINLCCID 96 (update from Level 92) | 4LCC3-0396 | $195.00 |
| SOLFEAS (initial purchase) | 3SOL3-1194 | $100.00 |
| Control Profile Macros for Lotus or Symphony | 3010-0388 | $35.00 |
| Design Week Creation Program | 3DWEE3-0494 | $35.00 |
| **BLAST 3.0 Documentation Set (Enter Quantity)** | | |
| Printed version in a 3-ring binder | 1001-0695 | $250.00 |

The last four digits of the catalog number indicate the month and year the item was released or published. This will enable you to see if you have the most recent version. All software will be shipped on 3.5" high density floppy disks unless noted otherwise.

# DOE-2 DIRECTORY

## Program Related Software and Services

***Contact the vendors for prices and ordering information***

## Mainframe and Workstation Versions of DOE-2

| | |
|---|---|
| **DOE-2.1D and 2.1E**<br>(Source code, executable code and documentation)<br>For 2.1E DEC-VAX, Order #000158-DOVAX-02<br>For 2.1E SUN-4, Order #000158-SUN-0000<br>For 2.1D DEC-VAX, Order #000158-D6220-01<br>For a complete listing of the software available from ESTSC order their "Software Listing" catalog ESTSC-2. [See *User News* Vol. 16, No. 3, p. 21] | Energy Science / Technology-<br>Software Center (ESTSC)<br>P.O. Box 1020<br>Oak Ridge, TN 37831-1020<br>Phone: (615) 576-2606<br>Fax: (615) 576-2865<br>ESTSC@ADONIS.OSTI.GOV<br>www.doe.gov/html/osti/ |
| **FTI-DOEv2.1E** (Source code and documentation)<br>Combined source code package for both VAX and SUN versions of DOE-2.1E. Available on most distribution formats and for most operating systems (1/4" QIC tape, TK50 tape, 3.5" floppy, etc). Note: this is the distribution package only, no executables. Complete documentation for DOE-2.1E, digitally reproduced, spiral bound, and separated into multi-volume sets. [See *User News* Vol. 12, No. 4, p. 16] | Finite Technologies, Inc<br>3763 Image Drive<br>Anchorage, AK 99504<br>Contact: Scott Henderson<br>Phone: (907) 333-8933<br>Fax: (907) 333-4482<br>info@finite-tech.com<br>www.finite- tech.com/fti/ |

## PC Versions of DOE-2

| | |
|---|---|
| **ADM-DOE2**<br>ADM-DOE2 (DOE-2.1E) is compiled for use on 386/486 PCs with a math co-processor and 4MB of RAM. It runs in a DOS or Windows environment and is a highly reliable and tested version of DOE-2 which contains all of the 1994/95 enhancements to the program. The package contains everything needed to run the program: program files, utilities, sample input files, and weather files. More than 300 weather files are available (TMY, TRY, WYEC, CTZ formats) for the U.S. and Canada. [See *User News* Vol. 7, No. 2, p. 6] | ADM Associates, Inc.<br>3239 Ramos Circle<br>Sacramento, CA 95827<br>Contact: Marla Sullivan, Sales<br>Phone: (916) 363-8383<br>Fax: (916) 363-1788 |
| **CECDOEDC (Version 1.0A)**<br>A microcomputer version of DOE-2.1D with a pre- and post-processor designed strictly for compliance use within the State of California. It generates some of the standard compliance forms as output. Order P40091009 for the CECDOEDC Program with Manuals. Order P40091010 for the DOE-2.1 California Compliance Manual. [See *User News* Vol. 12, No. 4, p. 13] | MS: 13 – Publication Office<br>California Energy Commission<br>P.O. Box 944295<br>Sacramento, CA 94244-2950<br>Phone: (916) 654-5106 |
| **EnergyPro (Win/DOE)**<br>A new Windows-based building energy analysis program designed to run on WindowsNT and Windows95. EnergyPro provides a next-generation interface for fast inputting and analyzing; including drag-and-drop, cut/copy/paste, and full graphic printout. Nonresidential modules include heating and cooling loads, California Title 24 Prescriptive Method compliance calculations, and tailored lighting calculations. A version of DOE-2 is available for use outside California. | Gabel-Dodd / EnergySoft, LLC<br>100 Galli Drive, Suite 1<br>Novato, CA 94949<br>Contact: Eric Walstad<br>Phone: (415) 883-5900<br>Fax: (415) 883-5790<br>Martyn@energysoft.com<br>www.energysoft.com |

*Caveat : We list third-party DOE-2-related products and services for the convenience of program users, with the understanding that the Simulation Research Group does not have the resources to check the DOE-2 program adaptations and utilities for accuracy or reliability.*

# PC Versions of DOE-2 (continued)

| | |
|---|---|
| **DOE-Plus**<br>DOE-Plus, a complete implementation of DOE-2.1D, is used to interactively input a building description, run DOE-2, and plot graphs of simulation results. Interactive error checking, context-sensitive help for all DOE-2 keywords, a 3-D view of the building that can be rotated, and several useful utilities.<br>Also from ITEM Systems:<br>**Demand Analyzer,** uses templates of building types and vintages to simplify DOE-2 input requirements. Online help feature.<br>**Prep,** a batch preprocessor, ideal for parametric studies, that enables conditional text substitution, expression evaluation, and spawning of other programs. [See *User News* Vol. 11, No. 4, p. 4 and Vol. 13, No. 2, p. 54, and Vol. 16, No. 1, p. 28-32 | ITEM Systems<br>321 High School Road NE, #344<br>Bainbridge Isl., WA 98110<br>Contact: Steve Byrne<br>Phone: (206) 855-9540<br>Fax: (206) 855-9541<br>byrne@item.com |
| **EZDOE**<br>EZDOE is an easy-to-use PC version of DOE-2.1D. It provides full screen, fill in the blank data entry, dynamic error checking, context-sensitive help, mouse support, graphic reports, a 750-page user manual, extensive weather data, and comprehensive customer support. EZDOE integrates the full calculation modules of DOE-2 into a powerful, full implementation of DOE-2 on DOS-based 386 and higher computers.<br>[See *User News* Vol. 14, No. 2, p. 10 and No. 4, p. 8-14] | Elite Software, Inc.<br>P.O. Drawer 1194<br>Bryan, TX 77806<br>Contact: Bill Smith<br>Phone: (409) 846-2340<br>Fax: (409) 846-4367<br>76070.621@compuserve.com |
| **FTI-DOEv2.1E**<br>Highly optimized version of DOE-2.1E software, available for most computing systems. Current support: MSDOS and Windows 3.x, Windows NT, OS/2, RS/6000 (AIX), NeXT, SUN, UNIX (most systems). Call for platforms not listed. Documentation and weather files are available. Also FTI-DOEv2.1E source code, highly optimized and portable version; will compile for most systems. [See *User News* Vol. 12, No. 4, p. 16] | Finite Technologies, Inc<br>821 N Street, #102<br>Anchorage, AK 99501<br>Contact: Scott Henderson<br>Phone: (907) 272-2714<br>Fax: (907) 274-5379<br>Info@finite-tech.com<br>www.finite-tech.com/fti/ |
| **MICRO-DOE2**ä<br>MICRO-DOE2 (2.1E), running in a DOS or Windows environment, is a widely used, reliable, and tested PC version of DOE-2.1E. It includes automatic weather processing, batch file creation, and a User's Guide with instructions on how to set up a RAM drive. System requirements: 386/486 PC with 4 MB of RAM and math co-processor.<br>Also from ACROSOFT/CAER Engineers:<br>**NETPath**, a network edition of MICRO-DOE2 for up to five users, allows you to store and run DOE-2 application files on one machine using input files from another machine. The result is improved space usage and project file management.<br>**POWERPath**, for single machines, allows you to keep MICRO-DOE2 application files in one directory and submit input from any other directory.<br>**BDL Builder** is a user-friendly Windows-implemented pre-processor for DOE-2.1E that allows the description of specific building and HVAC characteristics with numeric input by preparing databases, or building blocks, and then selecting records from the databases to assemble a complete input.<br>**E2BB** translates existing DOE-2.1E text input to BDL Builder.<br>**Weather Files** for most U.S., Canadian, and European cities are available in various formats, including TRY, TMY, CTZ, and WYEC.<br>[See *User News* Vol. 7, No. 4, p. 2; Vol. 11, No. 1, p. 2; Vol. 15, No. 1, p. 8; Vol. 15, No. 3, p. 4; Vol. 16, No. 2, p. 1,7; Vol. 16, No. 4, p. 7-8] | ACROSOFT / CAER Engineers<br>814 Eleventh Street<br>Denver, CO 80401<br>Contact: Don Croy<br>Phone: (303) 279-8136<br>Fax: (303) 279-0506<br>102447.2611@COMPUSERVE.COM |

# PC Versions of DOE-2 (continued)

| | |
|---|---|
| **PRC-DOE2**<br>A fast, robust and up-to-date PC version of DOE-2.1E. Runs in extended memory, is compatible with any VCPI compliant memory manager and includes its own disk caching. 377 weather data files available (TMY, TRY, WYEC, CTZ) for the U.S. and Canada<br>**PRC-TOOLS** is a set of PC programs that aids in extracting, analyzing and formatting hourly DOE-2 output. Determines energy use, demand, and cost for any number of end-uses and periods. Automatically creates 36-day load shapes. Custom programs also available. | Partnership for Resource Conservation<br>140 South 34th Street<br>Boulder, CO 80303<br>Contact: Paul Reeves<br>Phone: (303) 499-8611<br>FAX: (303) 554-1370<br>paulreeves@aol.com |
| **VisualDOE 2.5 for Windows ™**<br>VisualDOE 2.5, which uses DOE-2.1E as the calculation engine, enables architects and engineers to quickly evaluate the energy savings of HVAC and other building design options. Program is supported by a graphical interface and on-line help. Program includes climate data for the 16 California weather zones. A demo can be downloaded from http://www.eley.com. [See *User News* Vol. 15, No. 2, p. 10; Vol. 16, No. 4, p. 9-16; Vol. 17, No. 4, p. 8-13] | Eley & Associates<br>142 Minna Street<br>San Francisco, CA 94105<br>Charles Eley or John Kennedy<br>Phone: (415) 957-1977 / Fax: -1381<br>celey@eley.com<br>www.eley.com |

# Pre- and Post-Processors for DOE-2

| | |
|---|---|
| **DrawBDL**<br>DrawBDL, Version 2.02, is a graphic debugging and drawing tool for DOE-2 building geometry; it runs on PCs under Microsoft Windows. DrawBDL reads your BDL input and makes a rotatable 3D drawing of your building with walls, windows, and building shades shown in different colors for easy identification. [See *User News*, Vol. 14, No. 1, p. 5-7, Vol. 14, No. 4, p. 16-17, and Vol. 16, No. 1, p.37] | Joe Huang & Associates<br>6720 Potrero Avenue<br>El Cerrito, CA 91364<br><br>Contact: Joe Huang<br>Phone/Fax:: (510) 236-9238 |
| **Visualize-IT Visual Data Analysis Tools**<br>The ***Energy Information Tool*** is a Microsoft Windows 3.1 program for looking at and understanding metered or DOE-2.1E hourly input data. It provides the unprecedented ability to see all 8760 (or 35040) data points for a year's worth of data. You get an overview of the data with an EnergyPrint™ and can then explore the data with a variety of tools including load shapes, load duration curves, etc. This program requires a 486 computer and SVGA graphics capabilities.<br>The ***Calibration Tool*** is a Microsoft Windows 3.1 program for comparing DOE-2.1E hourly output data to total load and/or end-use metered data. Options include monthly demand and load 2D graphs, maximum and seasonal load shapes, average load profiles, end use residuals, monthly average week and weekend days, and dynamic comparison load shapes. This program requires a 486 computer and SVGA graphics capabilities. [See *User News* Vol. 17, No. 2, p. 2-6] | RLW Analytics, Inc.<br>1055 Broadway, Suite G<br>Sonoma, CA 95476<br>Contact:<br>Jim McCray<br>Pat Bailey<br>Jedd L. Parker<br><br>Phone: (707) 939-8823<br>Fax: (707) 939-9218<br>info@rlw.com<br>www.rlw.com |
| **D O E 1 2 3**<br>Uses Lotus 1-2-3 to graphically display DOE-2.1D output as bar charts, pie charts, and line graphs. [See *User News* Vol. 10, No. 3, p. 5] | Ernie Jessup<br>4977 Canoga Avenue<br>Woodland Hills, CA 91364<br>Phone: (818) 884-3997 |
| **Graphs for DOE-2**<br>2-D, 3-D, hourly, daily, and psychrometric plots [See *User News* Vol. 13, No. 1, p. 5] | Energy Systems Laboratory<br>Texas A&M University<br>College Station, TX 77843<br>Contact: Jeff Haberl<br>Phone : (409) 845-6065<br>Fax: (409) 862-2762 |
| **Pre-DOE**<br>A math pre-processor for BDL. | Nick Luick<br>19030 State Street<br>Corona, CA 91719<br>Phone: (714) 278-3131 |

# TOOLS AND TRAINING

| | |
|---|---|
| ***User News* (a quarterly newsletter)**<br>Sent without charge, the newsletter prints documentation updates and changes, bug fixes, inside tips on using the programs more effectively, and articles of special interest to users of DOE-2, BLAST, SPARK and their derivatives. The winter issue features an index of articles printed in all the back issues. Also available electronically at http://eande.lbl.gov/BTP/SRG/UNEWS | Simulation Research Group<br>Bldg. 90, Room 3147<br>Lawrence Berkeley National Laboratory<br>Berkeley, CA 94720<br>Contact: Kathy Ellington<br>Fax: (510) 486-4089<br>kathy@gundog.lbl.gov |
| **Help Desk Bruce Birdsall**<br>Call or fax Bruce Birdsall if you have a question about using DOE-2. If you need to fax an example of your problem to Bruce, please be sure to telephone him prior to sending the fax. This is a free service provided by the Simulation Research Group at Lawrence Berkeley National Laboratory. | Bruce Birdsall<br>Phone/Fax: (510) 829-8459<br><br>Monday through Friday<br>10 a.m. to 3 p.m. Pacific Time |
| **Training**<br>DOE-2 courses for beginning and advanced users. | Energy Simulation Specialists, Inc.<br>64 E. Broadway, Suite 230<br>Tempe, AZ 85282<br>Contact: Marlin Addison<br>Phone: (602) 784-4500 |
| **Instructional DOE-2 Video and Manual**<br>Takes you step-by-step in DOE-2.1D input preparation and output interpretation. | Contact: Dr. Moncef Krarti, Acting Director<br>JCEM/U. Colorado<br>CEAE Dept CB 428<br>Boulder, CO 80309-0428<br>Phone: (303) 492-3389 or 7317 |

**DOE-2.1E Bug Fixes via FTP**

If you have Internet access you can obtain the latest bug fixes to the LBNL version of DOE-2.1E by anonymous ftp. Here's how…

ftp to either gundog@lbl.gov or to 128.3.254.10
login: *type* anonymous
passwd: *type in your email address*

After logging on, go to directory pub/21e-mods ; bug fixes are in files that end with **.mod** . A description of the fixes is in file **VERSIONS.txt** in directory **pub** . Each fix has its own version number, ***nnn*** , which is printed out as DOE-2.1E- *nnn* on the DOE-2.1E banner page and output reports when the program is recompiled with the fix. You may direct questions about accessing or incorporating the bug fixes to Ender Erdem (ender@gundog.lbl.gov).

# WEATHER RESOURCES

| | |
|---|---|
| **TMY2** weather data for DOE-2. ENERGOS will provide TMY2 data for 239 cities converted for use with DOE-2 for PC versions of the program (DOE-2.1C through DOE-2.1E). | Kurmit Rockwell<br>ENERGOS<br>1705-14th Street, #401<br>Boulder, CO; 80302<br>Phone: (303) 499-7907 / Fax: (303) 449-7605 |
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## DOE-2 ENERGY CONSULTANTS

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| INTERNATIONAL DOE-2 ENERGY CONSULTANTS | |
|---|---|
| René Meldem (106034.630@compuserve.com)<br>Meldem Energie SA<br>Ch. De l'Ancienne Pointe 1<br>CH-1920 Martigny<br>Switzerland | Philip Schluchter<br>Institut fur Bauphysik Klein<br>Urs Graf-Strasse 1<br>CH4052 Basel<br>Switzerland |
| Andre Dewint<br>rue de Livourne 103/12<br>B-1050 BRUXELLES<br>Belgium | Gerhard Zweifel (Gzweifel@ztl.ch)<br>Zentralschweizerisches Technikum Luzern (ZTL)<br>Abt. HLK<br>CH-6048 Horw<br>Switzerland |
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## *Recent Reports: Tips for Daylighting with Windows*

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**LBNL-39945**

**TIPS FOR DAYLIGHTING WITH WINDOWS: The Integrated Approach**

**by**
**J. O'Connor, E. Lee, F. Rubinstein and S. Selkowitz**
**Energy & Environment Division**
**Lawrence Berkeley National Laboratory**
**Berkeley, CA 94720**

*Introduction:*
These guidelines provide an integrated approach to the cost-effective design of perimeter zones in new commercial buildings. The design method used in this document emphasizes that building decisions should be made within the context of the whole building as a single functioning systems rather than as an assembly of distinct parts. This *integrated* design approach looks at the ramifications of each individual system decision on the whole building.

The benefit of an integrated design approach is a greater chance of success towards long term comfort and sustained energy savings in the building.

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# Improved Procedures for Calibrating Hourly Simulation Models

**Tarek E. Bou-Saada and Jeff S. Haberl**
**Energy Systems Laboratory**
**Texas A&M University System**
**College Station, TX 77843**

**Abstract**
In order to improve upon previous calibration techniques, this article presents several new calibration methods including a 24-hour weather-daytype bin analysis to allow for the evaluation of hourly temperature and schedule dependent comparisons and a 52-week bin analysis to facilitate the evaluation of long-term trends. In addition, architectural rendering is suggested as a means of verifying the envelope dimensions and external shading placement. Several statistical methods are also reviewed to evaluate a goodness-of-fit including percent difference calculations, mean bias error (MBE), and the coefficient of variation of the root mean squared error (CV(RMSE)).

The procedures are applied to a case study daycare building in Washington, D.C. Nine months of hourly whole-building electricity data and site-specific weather data were measured and used with the DOE-2 building simulation program to test the new methods. The use of the new calibration procedures produced an hourly MBE of –0.7% and a CV(RMSE) of 23.1% which compare favorably with the most accurate hourly neural network models.

**Introduction**
With increased use of building energy simulation programs for evaluating energy conservation retrofits, calibration of the simulation program to measured data has been recognized as an important factor in substantiating how well the model fits data from a real building. The calibration of a simulation to measured monthly utility data has been the preferred method for many years. In the past few years, studies have reported calibrated models using hourly measured data. Most of the previous methods have relied on very simple graphical comparisons including bar charts, monthly percent difference time-series graphs, and monthly x-y scatter plots. Unfortunately, at hourly levels of calibration, many of the traditional graphical calibration techniques become overwhelmed with too many data points which makes it difficult to determine the central tendency of the black cloud of data points. A few advanced methods have been proposed including carpet plots and comparative 3-D time-series plots.

To date, no consensus standards have been published on calibration procedures that can generically be used on a wide variety of buildings. Historically, actual calibration has been an art form that inevitably relies heavily on user knowledge, past experience, statistical expertise, engineering judgment, and an abundance of trial and error. Typically, when a model is established as being calibrated (i.e., the user accuracy for electricity is near 5% per month), the author does not reveal the techniques used other than stating the final result. Hourly or daily error values are seldomly reported. A complete review of these and other methods is provided [BOU94].

**Methodology**
To simulate and calibrate a computer model to measured energy data of the case study site, several stages were completed. First, site specific hourly weather data were recorded which included dry bulb temperature, relative humidity, and peak wind speed (gathered from the nearby National Weather Service (NWS) station at the Washington National Airport) and global solar radiation data measured. The weather data were then joined into a single datafile and packed onto a TRY weather tape [BRO92] for use with the DOE-2 simulation program.

The calibration procedure also entailed creating a DOE-2 input file based on information obtained from site visits and architectural as-built plans. The hourly output report from the simulation was processed with post-processing routines [BRO92] specially modified for this work. This avoids the long-term data averaging encountered with monthly simulation comparisons [HIN91].

As-built drawings help to correctly dimension the building and calculate lighting and equipment levels. A site visit is generally essential to verify lighting counts and equipment nameplate data as well as to verify dimensions and any other miscellaneous discrepancies. The site visit should also include photographs of the building's surroundings for establishing shading calculations and detailed interviews with occupants, engineers, architects, and building operations personnel. Also included in the site visit should be shading measurements, and one-time RMS clamp-on Watt measurements of key pieces of equipment to verify actual power requirements. An HVAC system air balance report is also helpful when describing the zone air flow rates. On-site weather data measured for the simulation period have also been shown to significantly improve the simulation by Haberl[HAB95]. In cases where no weather data are available, standard weather tapes such as TRY and TMY may be used. Finally, many problems with the input file may be avoided simply by having prior knowledge of program expectations as well as a thorough engineering understanding of HVAC systems and buildings in general. After a simulation was performed in the current procedure, the Statistical Analysis Software [SAS89] program was used to analyze the goodness-of-fit and produce graphical feedback of the simulation progress. This includes time-series plots, bin plots, and three-dimensional hourly plots for further analysis [BOU94]. This allowed for a graphical comparison of the simulated consumption to the monitored consumption. Also included in this article is a technique for DOE-2 calibration that supplements the graphical comparison with a statistical comparison of the simulated and measured consumption which is described later. With this information now processed, the user can then decide if the model is calibrated to an acceptable level, and of equal importance, where the remaining mismatch may be located. This second feature is accomplished with the assistance of the calibration tools described in this article. If it is determined that a simulation is not fully calibrated, the areas where the simulated data do not match the measured data must be identified and adjusted in the input file. The DOE-2 program is run again and the data processed for comparison until an acceptable calibration is reached.

Figure 1 shows a view of the case study building using an architectural rendering program [HUA93]. It is one of a few software programs that have recently become available for purposes of rendering or viewing of building simulation input files. The software also includes such capabilities as rotating the building to allow for viewing from any direction with a three-dimensional perspective, a plan view, an elevation view, and a wire frame view. With a BDL visualization tool, each case study building envelope surface and shading surface can be inspected for proper placement, size, and orientation.

**New Calibration Methods**

Formerly, DOE-2 users were confined to using simple time-series plots [HIS88, HUN92, RED93] where simulated and actual data are superimposed upon the same graph for a short period of time. Although two-dimensional time-series plots are useful for determining certain features, a special problem exists when plotting long-term hourly time-series data. In such cases, direct comparison becomes ineffective for all practical purposes because it is very difficult to identify individual hourly data points. One improvement over past graphical techniques is shown in Figure 2 which shows an example of a binned analysis that was modified for this article from indices developed by [ABB93]. The superimposed and juxtaposed binned box-whisker-mean plots display the maximum, minimum, mean, median, 10$^{th}$, 25$^{th}$, 75$^{th}$, and 90$^{th}$ percentile points for each data bin for a given period of data. These plots eliminate data overlap and allow for a statistical characterization of the dense cloud of hourly points (scatter plots are still useful in showing individual point locations). The important feature to note about this plot is that the data are statistically binned by hour. This feature allows for the bin-by-bin goodness-of-fit to be evaluated. By using the box-whisker-mean plot combined with a scatter plot, one can visualize the data as a whole while simultaneously seeing the effects of the outliers in specific situations [TUK77, CLE 85].

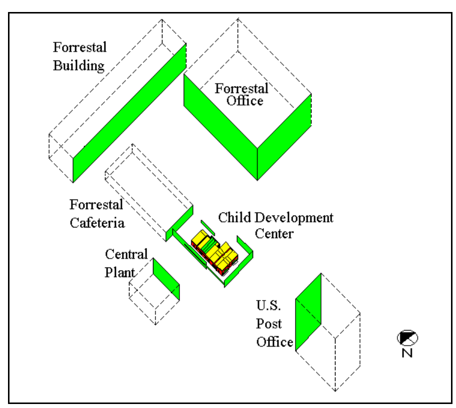


**Figure 1: The U.S.D.O.E. Forrestal complex and surrounding area. The solid planes represent shading from buildings, walls, and trees.**

Figure 2 is an example of a newly developed weekday/weekend 24-hour weather daytype box-whisker-mean plot that shows the whole-building electricity use versus the hour-of-the-day for both the measured data and the DOE-2 simulated data in three weather daytypes. The data are plotted using a technique developed by and modified [ABB93] for this article that includes a combination of vertical and horizontal juxtapositioning. Similar analysis can be performed with weekend and holiday data [BOU94]. One final feature of these plots is that the measured data mean is superimposed as a dashed line onto the calibrated DOE-2 simulation data. The difference between mean lines in each bin provides a measure of how well the model is calibrated at a specific bin. Likewise, the inter-quartile range (i.e., the distance between the 25 th and 75 th percentiles) represents the hourly variation in a given bin. The weather daytypes arbitrarily divide the measured data into temperatures below 45°F, between 45°F and 75°F, and above 75°F. The original concept for this plot can be traced to the weather daytype analysis developed by [HAD93].

This calibration procedure allows a DOE-2 user to view and analyze the weather and schedule dependent hourly energy use. The solid line in parts (b), (d), and (f) is the simulated mean. The dashed line is the measured mean line from parts (a), (c), and (e) that is superimposed onto the simulated data. These plots confirmed that the building's 24-hour electricity profiles are strongly influenced by the ambient temperature. The plots also provide a more efficient method of viewing the data based on heating only, no heating or cooling, and cooling only modes.

Comparative 3-D Surface Calibration Plots are also useful and can be found in Bronson [BRO92] and Bou-Saada [BOU94]. Figure 3 shows the same data as the 3-D surface plots, however, it displays the energy usage using 52-week time-series box-whisker-mean bins instead of temperature bins. The measured data are shown in part (a) and the DOE-2 simulation is shown in part (b). The x-axis in Figure 3 is the simulation week number; for this simulation, week "0" begins on April 1. The y-axis shows the whole-building electricity use in both (a) and (b).

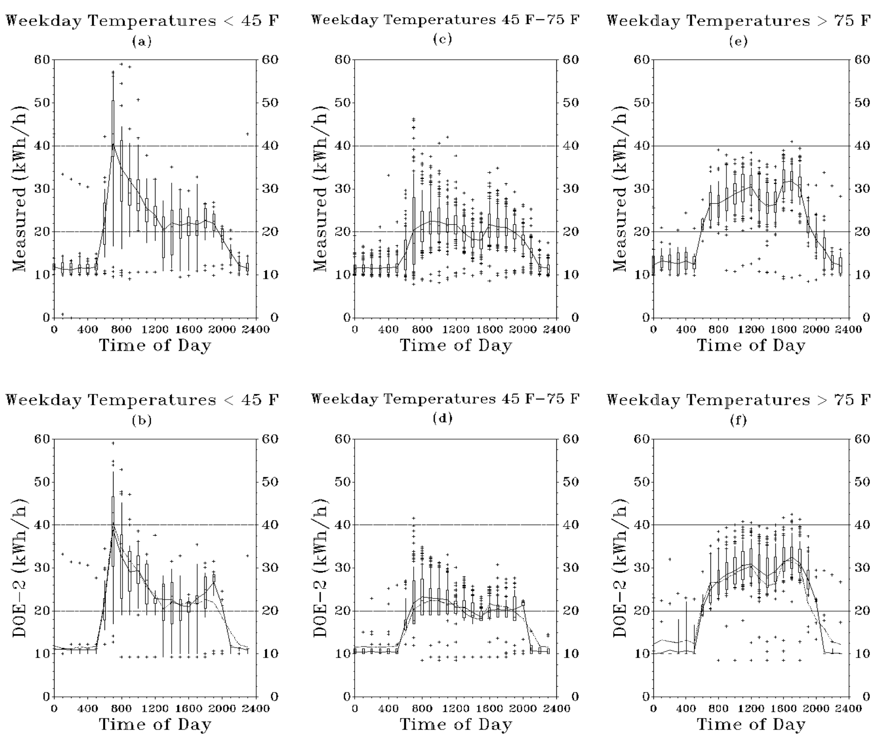

**Figure 2: Weekday 24-hour weather daytype box-whisker-mean plot.**

Figure 3 utilizes graphical superposition of the mean line from Figure 3(a) (dashed line) upon Figure 3(b) to further improve the viewing efficiency of the graph. It follows a similar path traced by the simulated data mean line represented by the solid line. Fine differences can also be seen in those points above the 90th percentile in weeks 0-5. Those points represent the hours of electrical resistance heating in the measured data that occurred when the staff manually switched on the baseboards in the toddler rooms to preheat the rooms prior to the arrival of the children.

When evaluating each set of paired weekly bins, it may be concluded that the average weekly simulated data seems to consistently track the average weekly measured data since the simulated box sizes (i.e., inter-quartile range) do not deviate significantly from the measured box sizes. However, the minimum simulated data limits are consistently lower in the DOE-2 plot (Figure 3(b)) further emphasizing the difficulties encountered in predicting the nighttime building shut down schedule. The consistency of the medium and minimum points seen in the winter is a characteristic of the DOE-2's rigid scheduling. It would appear that beginning in approximately week 12 and ending in week 17, the measured nighttime HVAC setback mode was overridden due to the zone temperature exceeding the control system upper setpoint temperature limit.

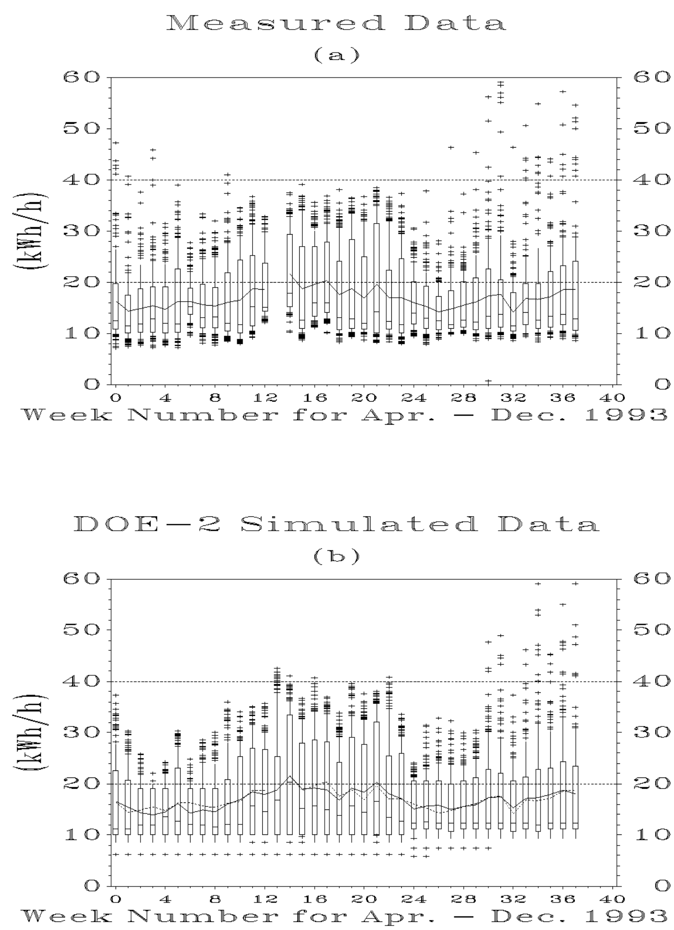


**Figure 3: 52-week binned box-whisker-mean plots.**

**Statistical Calibration Methods**

In the previous research [HAB95, BRO92], summed monthly simulation results and verified the calibration via a percent difference. Torres-Nunci [TOR89] and Hinchey [HIN91] only declared the model "calibrated", submitted hourly graphs to demonstrate the goodness-of-fit, and provided numerical differences only in the form of ± monthly differences. The problem with this approach is that the ± monthly difference does not provide a fine enough goodness-of-fit indicator and is in fact misleading because it can indicate a near perfect fit when there is still considerable hourly error in the calibration. Therefore, in the interest of furthering the calibration procedures, several statistical calculations were compared including monthly mean difference, hourly mean bias error (MBE) for each month, hourly root mean squared error (RMSE) reported monthly, and hourly coefficient of variation of the root mean squared error (CV(RMSE)) [KRE94a, KRE94b]. These indices were previously shown to be useful in comparing hourly neural network models against measured hourly use.
The mean bias error, MBE (%) [KRE94a, KRE94b], is a method with which to determine a non-dimensional bias measure (the sum of errors), between the simulated data and the measured data for each individual hour [KAT94]. The coefficient of variation of the root mean squared error, CV(RMSE) (%). [DRA81] is essentially the root mean squared error divided by the measured mean of the data. It is often convenient to report a non-dimensional result. CV(RMSE) allows one to determine how well a model fits the data; the lower the CV(RMSE), the better the calibration (the model in this case is the DOE-2 predicted data). Therefore, a CV(RMSE) is calculated for hourly data and presented on both a monthly summary and total data period.

The purpose of calculating the CV(RMSE) and comparing the results with the standard percent difference is to demonstrate that a percent difference report may be misleading. Since these calculations are usually shown for monthly simulations or even total simulation periods, the reader is never certain if the model is a true representation of the actual building or if the ± errors have canceled out. If one examines the hour-by-hour data results, it would be evident that each pair of points would in all likelihood be dissimilar and in some cases be significantly different, despite using the same measured weather data to drive the simulation model. Reporting monthly data therefore does not take into account the canceling out of individual differences observed when the simulation over-predicts during one hour and under-predicts during the next hour by approximately the same amount.

Despite all the months generally showing a low percent difference, the hourly CV(RMSE) consistently remained in the 20 to 27% range. This is still well within the range reported in a recent ASHRAE sponsored simulation competition that compared various modeling techniques including the winning model, a principle component, Bayesian non-linear complex neural network [KRE94a, KRE94b, MAC94]. Clearly, calibrations should be performed using both hourly CV(RMSE) and hourly MBE calculations rather than solely with the total percent difference calculation. These statistical indices serve to shed light on improving calibration techniques well into the future.

To represent the adequacy of the DOE-2 models from an initial workable model to a final calibrated model, each major change to the input file was documented through the research phase. A condensed set of iterations is graphically displayed in Figure 4 which shows the impact of most of the major modifications made to the model. In reality, about 100 different runs were made, however due to space constraints, summary groups of the runs are shown in the figure. For this article, both CV(RMSE) and MBE did not appear to further improve without major modifications to the input file such as additional schedules to account for differences in the occupants' behavior.

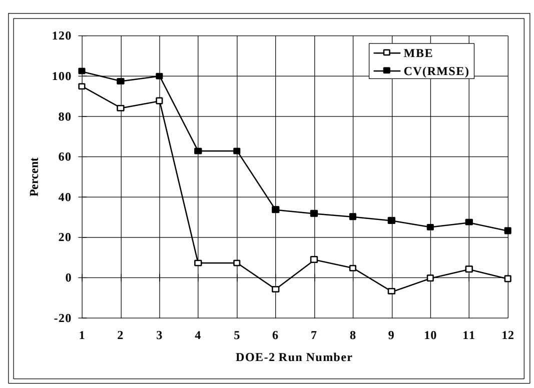


**Figure 4: Tuning progress with input modification.**

**Conclusions**

This article investigated techniques for improving calibrated computer building energy simulation methods and presented several new techniques for improving calibrations. The new methods include new graphical procedures and statistical goodness-of-fit parameters for quantitatively comparing simulated data to measured data. A four zone, single story electrically heated and cooled case study building was simulated with DOE-2 and calibrated using hourly measured whole-building electricity data and ambient weather conditions to demonstrate the new techniques.

These new techniques significantly improved the previous DOE-2 calibration methods. The long-term goal of this type of research is to eventually lead to a standardized calibration procedure that could be used on a wide variety of buildings and simulation codes. During this research effort, many valuable lessons were learned by refining the simulation. As a guide to future DOE-2 users, recommendations are provided in Bou-Saada and Haberl [BOU95] so that calibration efforts can be improved.

**Acknowledgments**

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DOE-2 Documentation Correction to the *DOE-2.1E Supplement*

# Saving Hourly Output for Postprocessing

Under the heading of "Saving Files of Hourly Output for Postprocessing" on p. 1.30 of the *DOE-2.1E Supplement*, please add the following information on how to save formatted ASCII files of DOE-2 hourly results so that they can be easily imported into postprocessing programs like Excel:

Using HOURLY-DATA-SAVE=FORMATTED in the LOADS-REPORT, SYSTEMS-REPORT, or PLANT-REPORT command produces an ASCII file containing the hourly data specified in the corresponding HOURLY-REPORT commands. The file produced is CEC1_0*n*.DAT, where *n*=1 for LOADS, 2 for SYSTEMS, and 3 for PLANT. Each line of the file contains month, day, hour followed by hourly values, all separated by one or more blanks. The first few lines of a file, starting with month 1, day 1, hour 1, and for three hourly variables, might look like this:

```
1  1  1    18.0    10.1    90.2
1  1  2    18.5    10.7    90.7
1  1  3    18.8    11.7    90.6
```

Note that the column headers (variable names and units) are not saved in the file, so you have to be careful that the values you import into your postprocessor have the meaning you think they do.

# DOE-2 PROGRAM DOCUMENTATION

DOE-2 documentation is available from two sources.

- The National Technical Information Service offers a complete set of DOE-2 manuals, available for purchase separately; prices and ordering information are below.
- The Energy Science Technology Software Center at Oak Ridge, TN, offers the DOE-2.1E updated documentation (which includes the *Supplement, Sample Run Book, and BDL Summary)* free of charge when you purchase the mainframe or workstation version of DOE-2. See the "DOE-2 Directory of Program Related Software and Services" in this issue for ESTSC's address.

Also, many of the PC vendors of DOE-2 offer some or all of the documentation when you buy their program. Names and addresses of all DOE-2 vendors are found in the "DOE-2 Directory of Program Related Software and Services" in this issue.

**To order any or all of the DOE-2 manuals from the National Technical Information Service:**

National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161
Phone (703) 487-4650, FAX (703) 321-8547, http://www.fedworld.gov/ntis/home.html

| Document Name | Order Number | Prices - 4/1/96 | Foreign Prices |
|---|---|---|---|
| DOE-2 Basics Manual (2.1E) | DE-940-13165 | 49.00 | |
| BDL Summary (2.1E) | DE-940-11217 | 28.00 | Double |
| Sample Run Book (2.1E) | DE-940-11216 | 100.00 | the |
| Reference Manual (2.1A) | LBL-8706, Rev.2 | 174.00 | prices |
| Supplement (2.1E) | DE-940-11218 | 100.00 | shown |
| Engineers Manual (2.1A) [algorithm descriptions] | DE-830-04575 | 57.00 | at left |

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