PRACTICAL EXPERIENCE IN ACHIEVING HIGH LEVELS OF ACCURACY IN ENERGY SIMULATIONS OF EXISTING BUILDINGS

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ABSTRACT

The computer simulation of existing buildings presents unique problems and opportunities. A high level of accuracy can only be achieved through optimization of three factors: (1) an intimate understanding of the simulation tool, (2) an intimate understanding of the building to be simulated, and (3) careful analysis and critique of output data. Optimization of these factors regularly produces computer simulations within 5% of the measured utility consumption. Examples of the optimization means are provided in this paper. In addition, one mainframe-based and two spreadsheet-based simulation tools are discussed in terms of their characteristics, proper application, and relative cost of use. Further discussion of the use of computerized simulation as a critical component of an energy services contract (shared savings/demand-side management) is provided.

INTRODUCTION

Starting in the mid-1970s, computer simulation of buildings was developed as a practical tool for the engineering of buildings. The tool has found significant use during the design phase of a building to develop load estimates and optimal combinations of building features. The tool has perhaps found even better use in the analysis of existing buildings for energy conservation retrofit. By simulating retrofit options on the computer, reliable estimates of potential energy savings may be achieved, assuming that the initial modeling and subsequent modeling of retrofit measures has been well done. In fact, the author has used a wide range of computer simulation tools over the past 10 years to prepare savings estimates for a large number of comprehensive energy retrofits in both large (1.8 million ft^2) and small (25,000 ft^2) buildings with great success.

In at least one case, a major energy services company declined to accept the conservative savings figures generated by computer modeling of the building, implemented a project based on its own optimistic estimates of savings, and is now writing its customer a check for more than $100,000 annually for the project's "shortfall" in savings from the optimistic estimates. Those optimistic estimates increased total estimated savings by more than $200,000 per year—fortunately (for them), the energy services company did not guarantee 100% of its estimated savings.

The importance of accurate modeling of existing buildings is clearly critical to the business of energy services, demand-side management, or any form of energy retrofit. This is even more important given the growing employment of demand-side management as a supply strategy by utility companies nationwide.

For a computer simulation of a building to be of value in evaluating energy retrofit opportunities, it must be accurate. To be "accurate," the model should account for essentially all of the sources and uses of energy in a building. Such a model would calculate a total energy consumption that is close to the building's actual annual energy use, say within 5%. Such a model would also closely mimic the actual seasonal variations in energy used by the building. Finally, such a model would allocate energy use by function in a faithful fashion. This last virtue is particularly important if the model is to be used to evaluate the effectiveness of specific energy retrofit measures, for example, lighting controls, outside air economizers, etc.

Accuracy in computer simulation of buildings, in our experience, is founded in three basic areas:

1. an intimate understanding of the simulation tool being used, including its various idiosyncracies and nuances;
2. an intimate understanding of the building being simulated, vis-a-vis its physical and operational characteristics—in essence, in existing buildings, the quality of the survey or "audit" determines the quality of the simulation; and
3. careful analysis and critique of output data (just because it is carefully prepared and computer generated doesn't mean it is correct)—our comments here generally apply to mainframe programs, though they also apply to other simulation tools.

By utilizing the above techniques, we have found it possible to regularly model buildings within 5% of their actual annual energy use with a high degree of confidence

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in the simulation of each energy-using system and functional use of energy in the building. It should be noted that, in buildings where weather is a strong energy-use factor, modeling to less than 10% variance from the actual energy use may be of limited value as our ability to predict weather for a given future year may not even be that accurate.

KNOWLEDGE OF THE TOOL

The first foundation of accurate building simulation is knowledge of the tool to be employed. While this statement may seem obvious, the computer simulation tools available to consulting engineers are very complex and have a "reality" of their own that cannot be ignored or violated if accurate models of buildings and energy retrofit measures are to be accomplished.

Very specific experience comes to mind in this regard having to do with assignment of lighting loads and quantities of outside air. It is fairly common to utilize return air troffer lighting fixtures to reduce the in-space load on supply air, thus allowing a lower supply air quantity and a raising of return air temperature that allows selection of a smaller cooling coil for the same cooling capacity. In one project during the design development stage, the engineer was modeling an office building that had a large amount of core space that served mostly as trafficways, secretarial space, and file/storage space. As a result, the principal cooling load was created by the lighting systems. Unfortunately, the design engineer assigned virtually all of the lighting load to the return air (which is not physically possible) and specified a minimum outside air quantity as a cfm/ft^2 figure. The result was that supply air was calculated by the program at something like 0.2 cfm/ft^2, the outside air was 0.1 cfm/ft^2, and the computer calculated a return air temperature of around 500 degrees. When half this return air was discarded, roughly half the cooling load went with it, for an amazing "savings" in energy use. Upon detailed examination of the computer output, we were able to point out the fallacy of the simulation and got the project back on track. The experience did make the point, however, that a lack of detailed understanding and familiarity with the calculational methodology of the simulation program can easily lead the modeler astray!

Another example is the capability or lack of capability to handle desired simulations by the program. Before variable-flow chilled-water pumping was commonly employed, few programs had the ability to simulate such a system. In order to do so, a series of "dummy" chillers were described to the program in such a manner that the program selected each in turn as loads increased. Associated with each of these "dummy" chillers was a constant-speed/power pump. The effect of each chiller-pump combination was to sequentially simulate the overall pump power curve that would be produced by a single variable-speed pump. For accurate estimation of savings, only the energy consumed by the pumping systems was compared from one run to the next, thereby eliminating unwanted secondary impacts such as changes in chiller efficiency.

To be knowledgeable about a simulation program, the user must understand how the input data are understood and utilized by the program, the calculations/algorithms employed by the program, the flow of input and calculated values through the program, and the precise effects various program "controls" exert on the calculations performed by the program. The bottom line here is that an inferior simulation tool in the hands of an engineer well-versed in its features and capabilities is superior to the best simulation tool in the hands of an engineer unfamiliar with it.

KNOWLEDGE OF THE BUILDING

Perhaps the single most important factor in developing accurate computer models of existing buildings is developing an intimate knowledge of the physical and operational characteristics of the building to be modeled.

Envelope and Weather vs. Operators and Controls

While many practitioners of computer simulation of buildings work toward more detailed time-related simulation of weather effects on building structures, those who are well acquainted with the practical aspects of building operation know that the effect of operating engineers and temperature control systems are much more dominant in affecting a building's energy use. Perhaps one or two anecdotes would be illustrative of this point.

In one study of a major high-rise office building in San Francisco, it was observed late one evening that the watch engineer was "fiddling" with the central temperature control panel. Immediately thereafter, the indicating instruments on the panel all began to change their values rapidly. Gently interrogating the watch engineer, it was learned that the "fiddling" was to put the outside air economizer control for the entire building back on "automatic." Further investigation revealed that it was this engineer's nightly practice to override these controls to place all operating HVAC systems (a few terminal reheat systems serving the entire core of the building) on 100% outside air! The reason for this was that the supply air for the engineer's office in the basement was return air from the core of the building and, by overwhelming the reheat coils with 100% outside air, the building core temperature dropped a few degrees and, in turn, cooled the engineer's office a few degrees. Modeling the building with automatic control of outside air would not have produced an accurate simulation. In fact, the building was modeled using an average outside air percentage of 70%. The very first output for the mainframe program simulation of this building showed a calculated energy use that was within 5% of the building's actual energy consumption.

In another downtown San Francisco high-rise, the chief engineer utilized a variety of electro-mechanical time clocks and "patch cords" to start and stop the building's various HVAC systems (he literally "plugged in" to whichever time clock he wanted a particular system to use). As he explained, he was then using the 7 a.m. to 6 p.m. time clock. Late-night observation, however, backed up by review of building electrical demand recordings, revealed that he had inadvertently "patched" himself into the time clock set for 6 a.m. to 7 p.m., resulting in a 10% to 12% increase in the building's HVAC energy use. Modeling this building based on scheduling information obtained from "the horse's mouth" could never have provided an accurate simulation.

Not only are operational practices much more dramatic in their effect than the effects of changes to the building envelope (which influence weather-related loads), but the whole issue of weather data is greatly misunderstood. Some building simulation programs have been criticized in the past for not providing 8,760 hours of actual weather data for simulations. The well-known mainframe program developed by the Department of Energy (DOE) and its various offspring provide 8,760 hours of simulation by means of a weather data source known as the "test reference year." Other programs, such as one developed by a well-known air-conditioning equipment manufacturer, provide a weather "trace" consisting of an average 24-hour profile for each month of the year, for a total of 288 hours of simulation. In truth, there is little if any meaningful difference between these methods for two reasons. The first reason is that the "test reference year" is not an actual year's weather data. It is, in fact, an amalgam of 12 actual month-long "chunks" of data. These months of real data are selected for incorporation into the reference year by a process that effectively chooses the mean month out of the months of data available. Given the continuous nature of our solar system and the statistical difference between an "average" and the "mean," the true difference between 8,760 hours of simulation and 288 is difficult to discern, except in the run-times of the various programs (which vary according to the number of hourly calculations that must be made). The second reason, which applies to new or existing buildings, relates to the purpose of performing a building simulation in the first place. The general thrust of any simulation is to project the future so as to make technical and economic decisions regarding building design features. All of this presupposes that the weather that will actually occur in the future period under consideration (3 to 10 years generally) will be essentially equal to the weather data being used for the simulation. Since this cannot be known for certain, any decision that would turn on the small effects in the calculations caused by the difference between 8,760 and 288 hours of simulation would be a decision of dubious wisdom at best.

Observational Surveys

As a result of experiences similar to the above, it has become our practice to perform two specific types of surveys in the buildings we study.

The first of these surveys is observational in nature and includes careful observation of the *functioning* of the building's temperature control systems—as opposed to simply reviewing the temperature control as-built drawings. We have found that frequently the controls were not installed as drawn, have been overridden (known as "auto-manual" control), or have simply failed in one fashion or another. This observational survey generally includes sample measurement of system operating parameters (supply air temperature, mixed air temperature, space discharge air temperature, etc.) as a means of observing the actual performance of the control system. The results of the inspection are frequently quite amazing!

The observational survey also regularly includes a "late night" tour of the facility and its HVAC systems to identify actual operating schedules (frequently at odds with what is reported by the operating engineers) and control system performance during this period. In one building surveyed, the control air compressor was off at night but the fans and pumps were still running—resulting in extreme overheating of the facility at night, which also made the chillers work hard in the morning to bring the building back down to temperature when the controls came back on! This late-night survey is also invaluable in confirming the operating schedules for lighting systems, which are frequently under the control of the custodial crew.

Electrical Load Surveys

The second type of survey we find essential is an electrical load survey. Where great accuracy is desired, such as in the modeling of large high-rise office buildings, every electrical panel and piece of equipment should have its instantaneous power draw measured. This can be done with a hand-held power factor meter, with the data recorded and entered into a spreadsheet developed just for this purpose (see Figure 1, which is a sample output page from such a spreadsheet). It should be noted that simply reading voltage and amperage is insufficiently accurate, as induction motors especially have very wide ranges of power factors (depending upon their loading) that can cause volt/amp readings to be in error by 50% or more when compared to true power draw. In addition to the instantaneous measurement of electrical loads, it is also important to look at specific large loads (chillers, elevators, computer rooms, etc.) over time, using a power-recording instrument. This instrument can also be used to observe the total power demand profile for the entire building if the building is small and time-of-day metering

DATE:12-14-83 to 1-12-84 RECORDED BY: JPW, JLH, MFS,RW

LOAD	TIME	AVE VOLTS	L-1	P.F.	L-2	P.F.	L-3	P.F.	KW	REMARKS
---NORTH TOWER-------------										------------------NOTE:FLOOR 31 IS AT BOTTOM
30 PNL 30A	1000	267.89	115	0.99	91	0.98	88	0.96	77.0	
30 AHU 30-3	"	267.89	19	0.84	19	0.91	17	0.91	13.1	
30 PNL 30AA2	"	267.89	3	0.82	5	0.63	9.9	0.88	3.8	
30 WINDOW WASHER	"	267.89	0	0.00	0	0.00	0	0.00	0.0	
30 PNL AA30	"	267.89	8	1.00	9	0.81	3	0.81	4.7	
30 AHU 30-4	"	267.89	15	0.81	17	0.82	17	0.73	10.3	
30 PNL 29AA2	"	120.09	9	0.93	11	1.00	23	1.00	5.1	WMR @ BOTTOM OF 30AA2
29 PNL A29	1000	267.89	129	0.99	95	0.96	85	0.98	81.0	
29 AHU 29-3	"	267.89	23	0.83	23	0.75	21	0.83	14.4	
29 AHU 29-4	"	267.89	19	0.77	17	0.83	19	0.85	12.0	
29 PNL AA29	"	267.89	19	0.88	23	0.52	11	0.98	10.6	
28 PNL A28	0945	267.89	141	0.97	93	0.94	99	0.94	85.0	
28 AHU 28-3	"	267.89	27	0.88	29	0.81	25	0.86	18.4	
28 AHU 28-4	"	267.89	19	0.62	15	0.65	17	0.76	9.2	
28 PNL AA28	"	267.89	3	0.72	3	0.99	7	0.82	2.9	
						DATE:		RECORDED BY:		
28 PNL 28AA2	"	267.89	3	1.00	11	0.83	10	0.64	5.0	
27 PNL A27	0930	267.89	103	0.97	71	0.96	81	0.95	65.6	
27 AHU 27-3	"	267.89	21	0.84	23	0.76	19	0.82	13.6	
27 AHU 27-4	"	267.89	19	0.78	16	0.83	14.9	0.89	11.1	
27 PNL AA27	"	267.89	3	0.85	5	0.87	7	0.93	3.6	
27 RADIO	"	267.89	0	0.00	0	0.00	0	0.00	0.0	
27 PNL 27AA2 WEST	"	120	17	0.96	17	1.00	10	1.00	5.2	WEST MECH ROOM
27 PNL 26AA2 WEST	"	120	9	0.96	15	0.71	9	0.97	3.4	READ @ BOTTOM OF 27AA2
26 PNL A26	0915	267.89	133	0.99	90	0.97	65	0.97	75.6	
26 AHU 26-3	"	267.89	19	0.87	19	0.78	17	0.82	12.1	
26 AHU 26-4	"	267.89	19	0.76	15	0.81	18	0.83	11.1	

Figure 1 Example of electrical load survey data tabulation.

is not employed by the utility company. Frequently, particularly for large buildings, the utility company records the building's power demand over time (utilizing magnetic tape or bubble memory meters) and the information from these meters is almost always available from the utility company (see Figure 2, which shows a 24-hour plot of utility company demand interval records).

As large buildings, even in cold climates, are usually in a cooling mode of HVAC system operation, electrical energy use makes up the vast majority of the building's energy use. This being the case, it is important to compare the sum of the various instantaneous load measurements with the recorded peak demand for the building, as shown in Figure 3. If the individual measurements don't equal the total demand, then any attempt at modeling will fail. Furthermore, a building's energy use is determined by connected loads multiplied by hours of use. By utilizing the data from the operational survey and checking it against the record of electrical demand over time, a high level of confidence can be achieved as to the actual operating schedules of the various energy-using systems in the building.

OUTPUT CRITIQUE

One of the hardest things to do in performing a building simulation is to honestly critique the computer

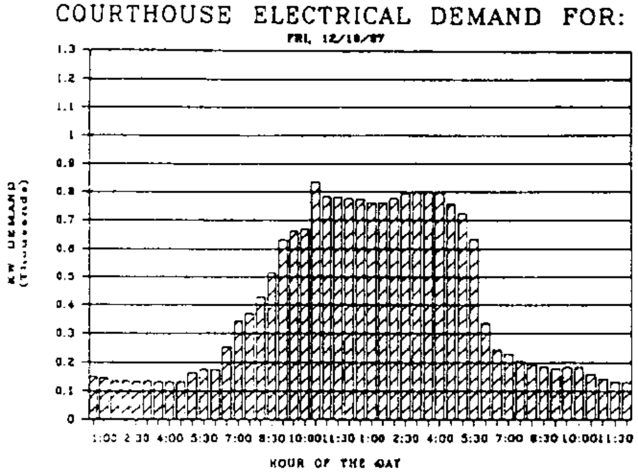

Figure 2 *Example of analysis of utility company demand interval records.*

output. After spending hours or even days preparing the input data, it is easy to fall into the trap of believing that the output must be correct. However, as our mistakes prove to us, it is critically important to critique the computer output with a skeptical attitude. Three specific techniques are valuable with regard to critiquing simulation program output.

Annual Energy-Use Profile Comparison

The first technique is a gross, year-long evaluation of the modeled energy use in comparison to actual energy use. While the totals may agree, seasonal variations may not agree well with each other, indicating that weather-influenced systems are not modeled well. Graphic comparison of modeled and actual energy use is most valuable in this evaluation, as can be seen in Figures 4 and 5. In addition, since computer simulations generally utilize weather data that are a composite of multiple years' data

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COUNTY COURTHOUSE MEASURED DEMAND

ELECTRICAL LOAD                          KW
-----------------------------------------------
MISC POWER & LIGHTING COMBINED        330.9
MECHANICAL EQUIP:
AIR HANDLERS                           82.0
RETURN & EXH FANS                      32.9
PRI. HOT WATER PUMP                     2.2
CONTROL TRANS                           0.6
COMP. RM.                               2.0
OIL BURN PNL #4                         6.1
COMP. RM PNL # 4                        4.4
MCC SF #1 MEZZ                         10.3
AIR CONTROL COMPRESSOR                  4.2
BOILER RM EXH FAN #3                    0.4
PUMP PANEL #2                           4.5
PENT PNL #15 & 16                       2.7
AMP PNL (CHILL RM)                      0.2
RM PNL 17                               3.3
NEW PNL RM 8                            0.7
3RD FLR FANS                           23.7
N. COURTROOM FANS                      14.5
S. COURTROOM FANS                      15.7
PANEL #18182                           39.4
9-11TH FAN                             22.4
-----------------------------------------------
SUB TOTAL                             603.1

CHRY CHILLER LOAD FROM DRANETZ        175.0
CHW PUMP                                6.0
CW PUMP                                 6.0
TOWER FAN                               9.0
-----------------------------------------------
SUB TOTAL                             196.0

TOTAL MEASURED KW DEMAND              799.1

UTILITY CO. DEMAND (WINTER)           800.0

PERCENT VARIANCE                        0.1
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Figure 3 *Example of comparison of field-measured electrical loads to peak demand recorded by the utility company.*

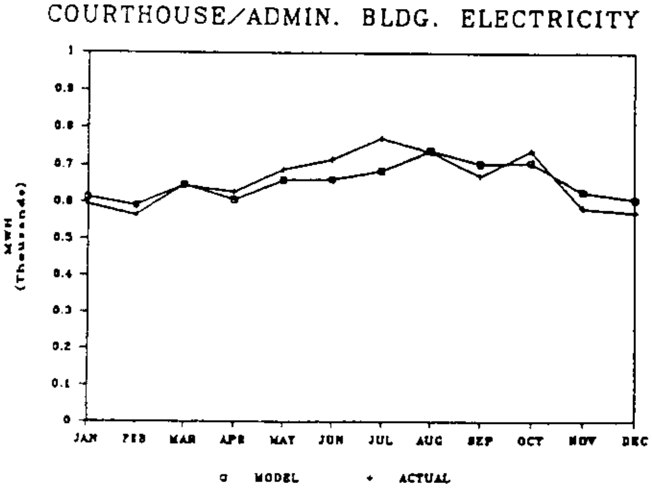


Figure 4 *Comparison of model and actual annual electrical use profile.*

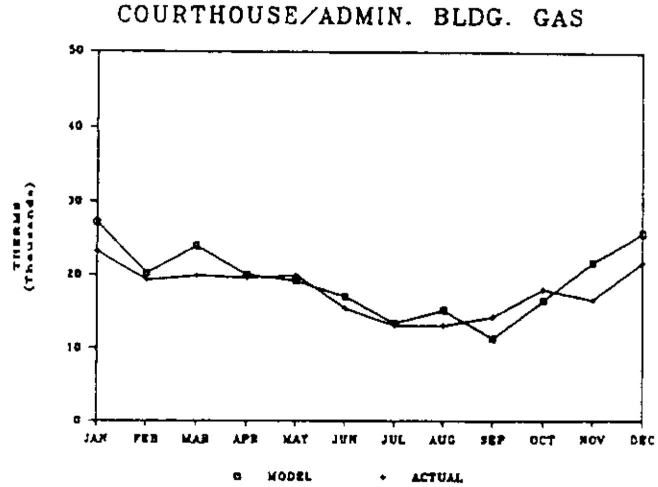


Figure 5 *Comparison of model and actual annual natural gas use profile.*

(including NOAA's "TRY" tapes as previously discussed), it is valuable to contrast the actual weather data for the year being modeled to the weather data employed in the simulation, as shown in Figure 6. When modeling a building using a year's worth of actual energy use for validation, it is more important that the modeled energy use vary according to the changes in the model weather for the same period rather than absolutely agree with the actual utility data being used for comparison. For example, if the model shows higher than actual electrical use for cooling in a given month and both the actual electrical use and actual temperatures are lower than the model, then this lends credence to the model and means the model is meaningful for evaluation of multiple future years' potential for energy savings.

Peak Load Comparison

The second of these techniques is to evaluate peak modeled loads against known values. From the utility company's data, the building's peak electrical demand is known for all seasons of the year. Generally, computer models will provide a monthly peak electrical demand for the various components of the model. By comparing the principal seasons (summer, fall/spring, and winter), it can be observed whether all of the loads measured during the survey found their way into the model and whether the seasonal modeling of cooling loads is correct. Furthermore, the building's peak cooling load is probably known from operating engineers' observations and/or operating logs, and this too, can be used as a scale of measure for evaluating the accuracy of the computer model. Again, the issue of the weather data employed for the simulation must be taken into consideration. Generally, all weather data used for simulations are missing the hottest and coldest days of the year. Accordingly, the actual demand data used for comparison would best be selected as a day experiencing the same, or nearly the same, temperature extremes as present in the weather data used for simulation. Interestingly enough, one building we modeled had one of its chillers fail and was short of capacity to support anything close to a "design" day. As part of assessing the comfort "risk" caused by the failed chiller, the mainframe simulation output was reviewed and we identified the ambient temperature at which the simulation would predict "losing" the building on a hot day. In fact, within a few weeks of completing the modeling process, an unseasonably hot day was encountered with a peak temperature exceeding our predicted "lose the building" temperature by a few degrees. Indeed, the chief engineer reported that he had "lost" the building on that one day.

Detailed Output Analysis

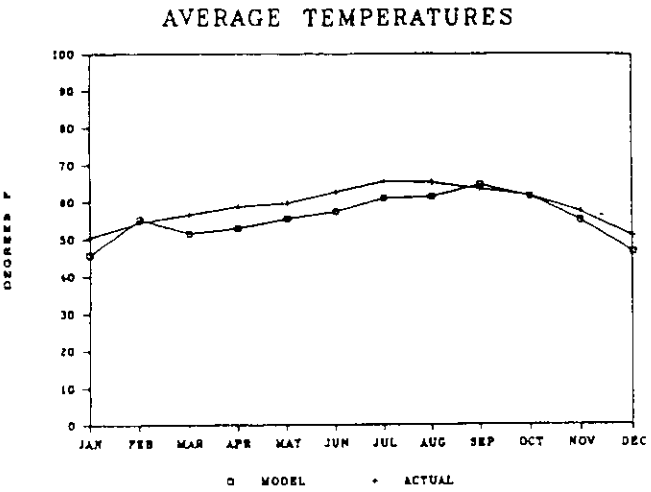
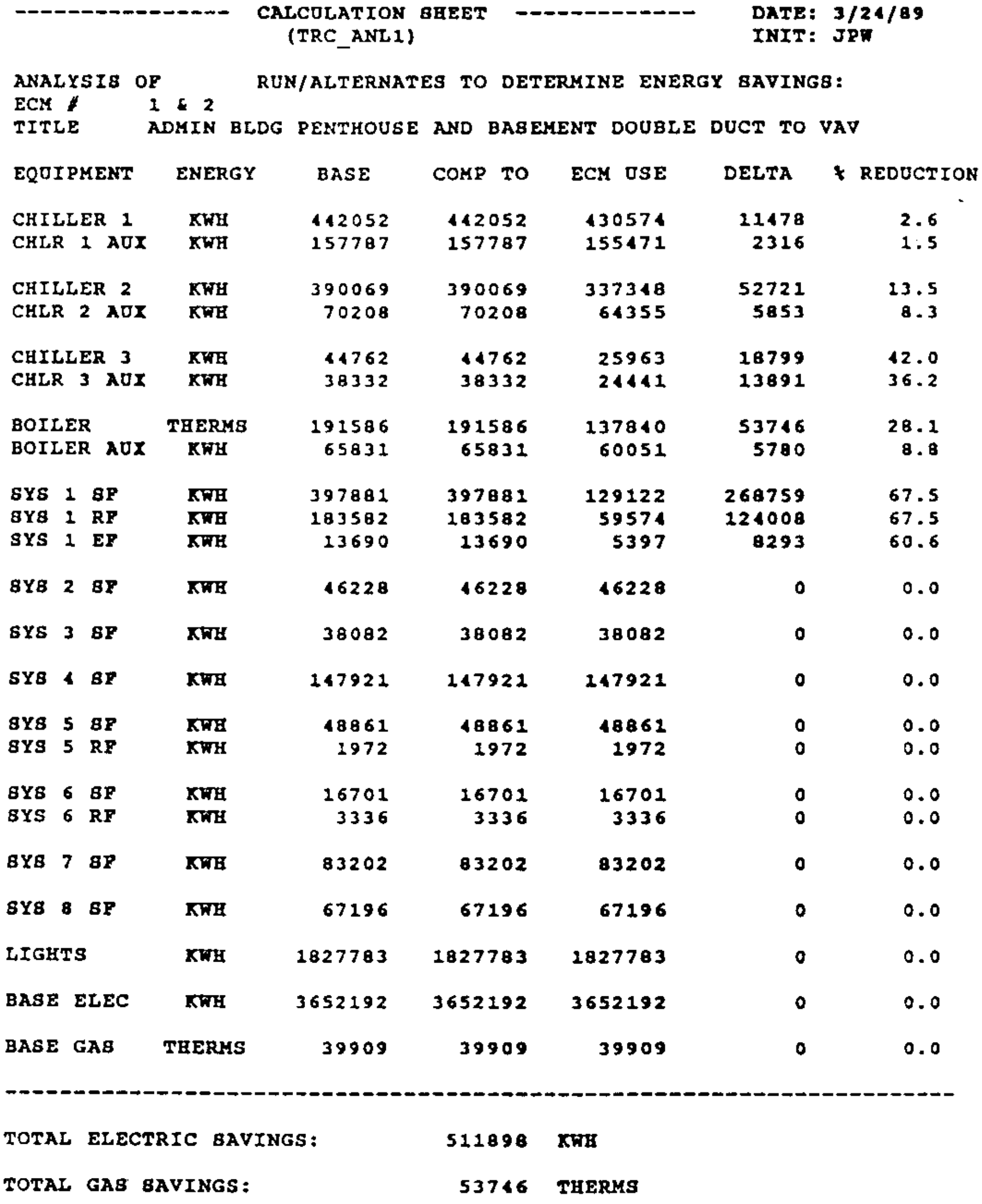


Figure 6 *Comparison of model and actual weather data.*

The third technique is primarily oriented toward evaluation of energy retrofit models. In order to develop savings estimates for energy retrofit measures under consideration, the retrofit is modeled and then contrasted with the original model, thus showing the savings that might be achieved. Since it is very easy to make small errors in editing the input data for a computer model and cause an unintended result, a useful quality control technique has been to analyze the computer model in detail (by functional use, i.e., lighting, cooling, fans, pumps, etc.) and develop a specific figure for the savings estimated for each retrofit in each functional use area. As can be seen in Figure 7, a very detailed analysis of the output from a mainframe proprietary computer model is possible. The analysis allows a "plausibility" check of the savings from a particular retrofit. For example, if a variable-air-volume retrofit is under consideration, it is possible to develop a specific estimate for the savings to be achieved by the fan alone. These savings can then be compared to the original energy used by the fan and the plausibility thereof evaluated. If a simple inlet vane conversion is anticipated and the system operates a single shift per day during weekdays, a savings figure in the neighbor hood of 30% to 40% might be anticipated on a "rule of thumb" basis. If the detailed analysis indicates a savings of 70% or 80%, then review of the model input is warranted to determine the error in the input or determine the reason that a savings figure much higher than the engineer's "rule of thumb" is reasonable. For example, perhaps the system does, after all, operate on a 24-hour-per-day basis or was grossly oversized and will experience very low loads compared to its installed capacity for most of its operating hours. In any event, when the savings vary greatly from what is "plausible," it indicates either an error in the modeling or an error in the plausibility logic—either of which should be determined before using the savings numbers generated by the model.

It is theoretically possible to create a "perfect" model in which every small unique thermal zone in a building responds to weather inputs virtually the same as



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----------------  CALCULATION SHEET  -------------     DATE: 3/24/89
                    (TRC_ANL1)                          INIT: JPW

ANALYSIS OF        RUN/ALTERNATES TO DETERMINE ENERGY SAVINGS:
ECM #      1 & 2
TITLE      ADMIN BLDG PENTHOUSE AND BASEMENT DOUBLE DUCT TO VAV

EQUIPMENT   ENERGY     BASE     COMP TO    ECM USE     DELTA   % REDUCTION

CHILLER 1    KWH      442052    442052     430574     11478        2.6
CHLR 1 AUX   KWH      157787    157787     155471      2316        1.5

CHILLER 2    KWH      390069    390069     337348     52721       13.5
CHLR 2 AUX   KWH       70208     70208      64355      5853        8.3

CHILLER 3    KWH       44762     44762      25963     18799       42.0
CHLR 3 AUX   KWH       38332     38332      24441     13891       36.2

BOILER      THERMS    191586    191586     137840     53746       28.1
BOILER AUX   KWH       65831     65831      60051      5780        8.8

SYS 1 SF     KWH      397881    397881     129122    268759       67.5
SYS 1 RF     KWH      183582    183582      59574    124008       67.5
SYS 1 EF     KWH       13690     13690       5397      8293       60.6

SYS 2 SF     KWH       46228     46228      46228         0        0.0

SYS 3 SF     KWH       38082     38082      38082         0        0.0

SYS 4 SF     KWH      147921    147921     147921         0        0.0

SYS 5 SF     KWH       48861     48861      48861         0        0.0
SYS 5 RF     KWH        1972      1972       1972         0        0.0

SYS 6 SF     KWH       16701     16701      16701         0        0.0
SYS 6 RF     KWH        3336      3336       3336         0        0.0

SYS 7 SF     KWH       83202     83202      83202         0        0.0

SYS 8 SF     KWH       67196     67196      67196         0        0.0

LIGHTS       KWH     1827783   1827783    1827783         0        0.0

BASE ELEC    KWH     3652192   3652192    3652192         0        0.0

BASE GAS    THERMS     39909     39909      39909         0        0.0
---------------------------------------------------------------------

TOTAL ELECTRIC SAVINGS:          511898  KWH

TOTAL GAS SAVINGS:                53746  THERMS
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Figure 7 Example of detailed analysis of output from mainframe simulation.

the actual building. However, the practicality of such modeling is doubtful, as the engineering costs to prepare such a model may actually exceed the value to be created by the modeling process, particularly in smaller buildings. As a result, even the best modeling tools and reasonably constructed models will be limited in their ability to predict the effect of retrofit measures. Therefore, in some cases, it is an appropriate engineering step to derate or discount the savings figures for *engineering* conservatism (see Figure 8 for example). A good example of this is the fact that many computer models that utilize hourly heating and cooling load calculations as part of their modeling (not all do, as will be seen below) are unable, without micro-zoning of the model, to avoid the sharing of internal heat gain with external zones needing heating, thus underestimating the actual heating requirements of the building. Similarly, tall buildings in central city locations often have large vertical exterior zones, part of which need cooling and part of which need heating at any given time, primarily due to solar exposure and shading from adjacent buildings. These perimeter systems can be difficult to model and sometimes will show optimistic results from even the most conservative attempts at modeling—thus necessitating an engineering discounting of savings. The bottom line here is that even the best models still have limits to their capabilities.

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----------------  CALCULATION SHEET  ---------------  DATE: 10/27/88
                      (BB_SAV3)                        INIT: JPW

SAVINGS FROM BEST COMPUTER MODELS:

 ECM# 1   RUN DESCRIPTION                      KWH       THERMS

          PENTHOUSE UNIT BASELINE            284146       32712

          PENTHOUSE UNIT OPT S/S             265684       28471
                                           ---------  ---------
           SAVINGS                            18462        4241

          PLAUSIBILITY FACTOR                  1.00        1.00

          NET SAVINGS                         18462        4241

          (NOTE, KWH INCLUDES ONLY COOLING AND FANS)
----------------------------------------------------------------------
 ECM# 2   RUN DESCRIPTION                      KWH       THERMS

          PENTHOUSE UNIT OPT S/S             265684       28471

          PENTHOUSE UNIT VAV                 133832        4156
                                           ---------  ---------
           SAVINGS                           131852       24315

          PLAUSIBILITY FACTOR                  0.75        0.60

          NET SAVINGS                         98889       14589

          (NOTE, KWH INCLUDES ONLY COOLING AND FANS)
----------------------------------------------------------------------
 ECM# _   RUN DESCRIPTION                      KWH       THERMS

             N/A                                  0           0

             N/A                                  0           0
                                           ---------  ---------
           SAVINGS                                0           0

          PLAUSIBILITY FACTOR                  1.00        1.00

          NET SAVINGS                             0           0

          (NOTE, KWH INCLUDES ONLY COOLING AND FANS)
```

Figure 8 *Example of conservative derating of energy savings from spreadsheet simulation program.*

Plausibility Check

Finally, by summing all the savings for all retrofits, a gross plausibility check can be performed, based on engineering judgment regarding whole building energy-use levels that are reasonable for the type of building being evaluated. This is a gross measure, but it is an excellent *final* check on the entire process, as shown in Figure 9. Even such a simple check can be effective in catching unreasonable optimism in energy savings estimates that may have slipped through all the other quality control measures in this very complex process of building simulation. Had such a macro check been part of the project documentation associated with the project mentioned in the introduction, that energy services company would not have the problem it currently faces.

SIMULATION TOOLS

It is likely that a wide range of opinion exists in the energy engineering field as to what constitutes "building energy simulation." Our view is a rather broad one and encompasses a wide range of calculational strategies as being appropriate to specific project goals and project environments.

```
---------------- CALCULATION SHEET ------------    DATE: 4/5/89
                  (CABC_SUM)                        INIT: JPW

                  ENERGY SAVINGS SUMMARY

ENERGY CONSERVATION MEASURE:                 KWH      THERMS      $$$

1.  ADMIN PENTHOUSE DOUBLE DUCT TO VAV
           &
2.  ADMIN BASEMENT DOUBLE DUCT TO VAV      511898     53746    $62,246

3.  ADMIN COURTROOM MULTIZONES TO VAV       37124      3589     $4,415

4.  CONVERT JAIL MULTIZONES TO VAV          53579         0
           &
7.  LARGE COURTHOUSE MULTIZONES TO VAV     127761     36682
                                         --------- ---------
                             SUB TOTAL     181340     36682    $27,696

5.  SUPERVISOR'S AHU CONTROL MOD            12372       332     $1,195

6.  LIGHTING RETROFIT                      448987     -1946    $38,888

8.  COURTHOUSE SMALL MZ'S TO VAV
           &
9.  COURTHOUSE SMALL MZ TO VAV             148703     43771    $27,093

10. SUMMER STEAM SHUT-DOWN                      0     10287     $3,292

11. ENERGY MANAGEMENT COMPUTER              74974      6190

                                            63146         0
                                         --------- ---------
                             SUB TOTAL     138120      6190    $14,135

12. VARIABLE FLOW CHILLED WATER             15647         0     $1,377

                             BTU/SF/YR
                                         --------- --------- ---------
   TOTAL (EXCL ECM#12)          43680     1478544    152651   $178,960

   PLAUSIBILITY FACTOR                       0.95      0.95

   NET SAVINGS                  41496     1404617    145018   $170,012
                             ========= ========= ========= =========
   EXISTING CONSUMPTION        104035     7896022    214272   $763,417

   PERCENT REDUCTIONS            39.9        17.8      67.7       22.3

   RETROFIT BTU/SF/YR           60355

 NOTE:
     1. ELECTRICITY AVERAGE UNIT COST FOR 12 MO. ENDING OCT '88
        WAS $0.0796/KWH, PLUS APPROX 10%      RATE INCREASE IN JAN
        '89 EQUALS $0.088/KWH USED ABOVE.
     2. NATURAL GAS UNIT COST USED IS $0.32/THERM.  SEE GAS RATE
        SCHEDULE ANALYSIS IN ENERGY SAVINGS CALCULATIONS APPENDIX.
```

Figure 9   Example of "gross" or "overview" check of savings calculations.

Mainframe Programs

The high end of the practice are programs that have traditionally run on mainframe (or mini) computers. Both proprietary and public-domain programs are in common use. The availability of such programs to run on high-end personal computers is becoming fairly commonplace. In general these programs have similar, if not common, ancestry and are founded in hourly heating and cooling load calculations that are then applied to the HVAC systems and equipment described to the program. These programs are very powerful simulation tools in that they allow for detailed input of both the envelope and the lighting and HVAC systems employed in the building, and produce excellent results (as shown in Figures 4 and 5). In addition, these programs also provide extensive output data for use in output critique. While very powerful, these programs require significant engineering labor to prepare the data necessary for input (often 40 to 80 engineering labor hours) and are sometimes too costly for use on smaller buildings or for use in the qualification of sales prospects in the energy retrofit business. To meet the need for less costly simulation methods, we developed some spreadsheet-based simulation tools that have proved to be very effective.

Complex Spreadsheet Simulation Tool

One of the spreadsheet-based tools developed is a complex spreadsheet that allows time-related loads to be scheduled by hour, by three day types (weekday, Saturday, and Sunday/holiday), by type of energy used, or by type of functional energy use (cooling, fans, lighting, etc.). In addition, the calendar of day types for the model year can be customized to cover virtually any situation. With respect to weather-related loads, the model takes a totally different approach than mainframe programs. In this case, the program accepts peak loads as inputs and distributes the load over the period of a year according to the differential between the modeled ambient temperature and user-input "no-load" temperatures for heating and cooling. Other variables include heating and cooling lockout temperatures, minimum loads, and daily and seasonal operating schedules. The model calculates hourly ambient temperatures for application of the loads by using a near-sinusoidal model and varying the temperature up or down from the average temperature by half the average daily range. The model utilizes as input degree-days and average daily range by month or average maximum and minimum temperatures by month. The model provides hourly heating and cooling loads for typical day types each month and hourly time-related loads for typical day types each month.

As can be concluded from observation of Figures 10 and 11, this modeling tool can produce simulations of high accuracy and requires only a few hours for input generation and model runs. In addition, because there is great control over the model, many different retrofit measures can be modeled and custom simulations can be produced by modifying the code or extracting output from the base building model and performing subsequent calculations thereon. This tool is most effective on smaller or simpler buildings, where a high level of confidence in energy-savings figures is desired but engineering costs must be kept to a minimum.

Simple Spreadsheet Simulation Tool

Another tool we developed is a one-page simulation spreadsheet. Its purpose was to provide an extremely quick and inexpensive simulation tool for use where limited accuracy is acceptable and simulation costs are of greater importance than accuracy. Two versions of this model exist, one for HVAC systems that mix heating and cooling (e.g., terminal reheat) and one for nonmixing systems. As shown in Figure 12, this simulation tool has very simplistic input and basically views a building as having lighting, heating, cooling, HVAC accessories, domestic hot water, and two types of miscellaneous energy use (electrical and heating fuel). Inputs are generally in units per square feet (e.g., lighting input is in watts per square foot) and percentage of operating hours. In addition, provision is made for reduced summer operation (primarily for schools) and "off-hours" loads in all functional areas. Time-related loads are calculated based on "hours on" times input loads, similar to the spreadsheet described above, without the ability to customize day types or the annual calendar. Weather-related loads assume a linear, directly proportional relationship with degree-days, which are input to the spreadsheet.

This model was developed to simulate a college campus of more than 100 buildings, all of which had fairly simple HVAC systems. This tool was also used to

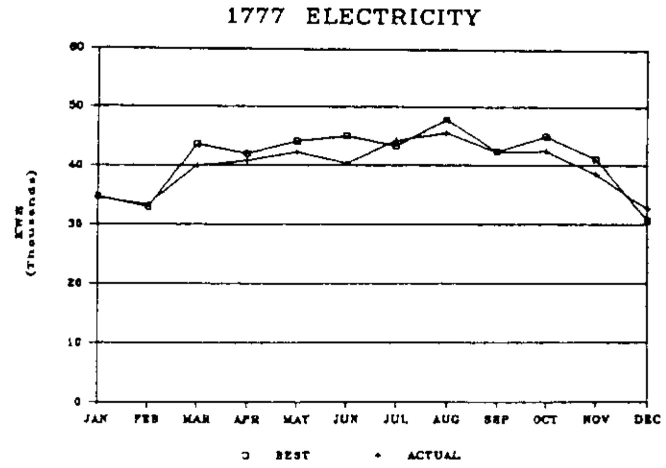


Figure 10 *Example of spreadsheet simulation program results.*

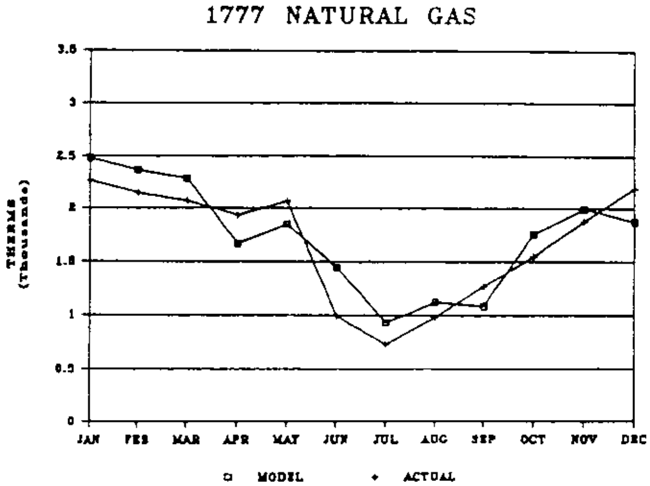
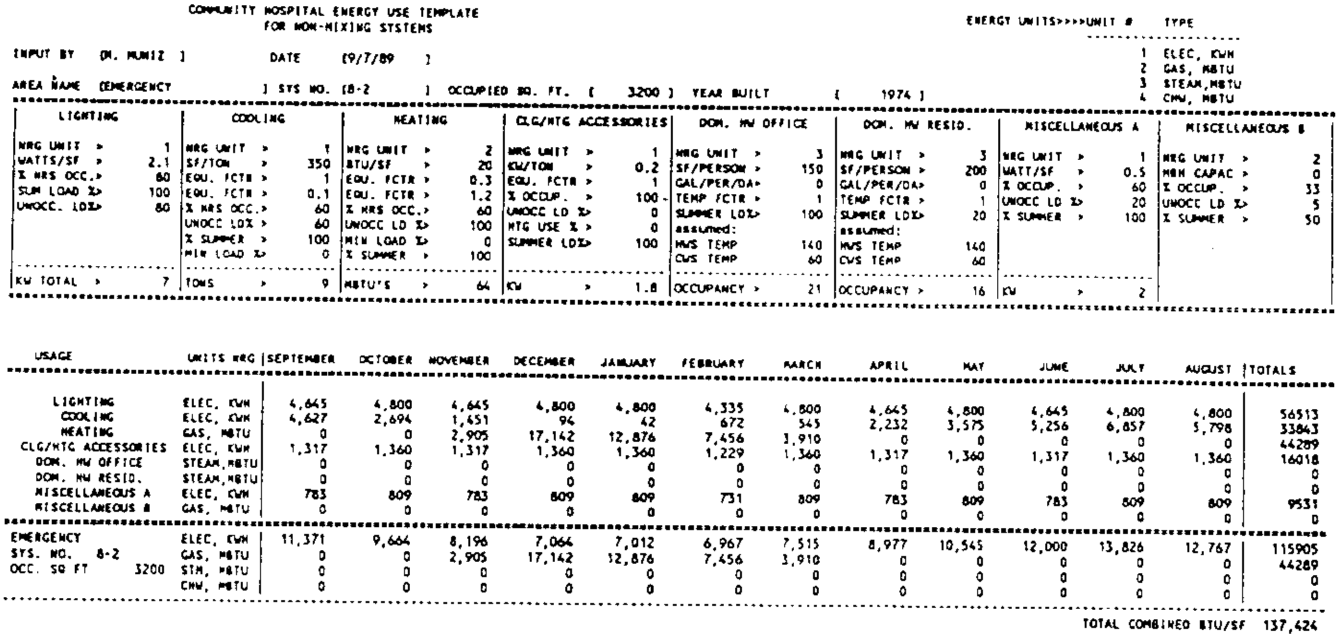


Figure 11 *Example of spreadsheet simulation program results.*



```
                    COMMUNITY HOSPITAL ENERGY USE TEMPLATE                                                   ENERGY UNITS>>>>UNIT #   TYPE
                           FOR NON-MIXING SYSTEMS                                                                          ---------------------
INPUT BY   [M. MUNIZ ]            DATE      [9/7/89    ]                                                                    1  ELEC, KWH
                                                                                                                            2  GAS, MBTU
AREA NAME  [EMERGENCY              ] SYS NO. [8-2       ]  OCCUPIED SQ. FT.  [    3200 ]  YEAR BUILT         [     1974 ]   3  STEAM,MBTU
                                                                                                                            4  CHW, MBTU
*******************************************************************************************************************************************
|      LIGHTING        |       COOLING         |        HEATING        | CLG/HTG ACCESSORIES |    DOM. HW OFFICE     |     DOM. HW RESID.      |   MISCELLANEOUS A     |    MISCELLANEOUS B    |
|                      |                       |                       |                     |                       |                         |                       |                       |
|NRG UNIT  >         1 |NRG UNIT   >         1 |NRG UNIT  >          2 |NRG UNIT   >       1 |NRG UNIT   >         3 |NRG UNIT   >           3 |NRG UNIT  >          1 |NRG UNIT   >         2 |
|WATTS/SF  >       2.1 |SF/TON     >       350 |BTU/SF    >         20 |KW/TON     >     0.2 |SF/PERSON >        150 |SF/PERSON >          200 |WATT/SF   >        0.5 |MBH CAPAC >          0 |
|% HRS OCC.>        60 |EQU. FCTR >          1 |EQU. FCTR >        0.3 |EQU. FCTR >        1 |GAL/PER/DA>          0 |GAL/PER/DA>            0 |% OCCUP.  >         60 |% OCCUP.   >        33 |
|SUM LOAD %>       100 |EQU. FCTR >        0.1 |EQU. FCTR >        1.2 |% OCCUP.   >     100 -|TEMP FCTR >          1 |TEMP FCTR >            1 |UNOCC LD %>         20 |UNOCC LD %>          5 |
|UNOCC. LD%>        80 |% HRS OCC.>         60 |% HRS OCC.>         60 |UNOCC LD %>        0 |SUMMER LD%>        100 |SUMMER LD%>           20 |% SUMMER  >        100 |% SUMMER   >        50 |
|                      |UNOCC LD% >         60 |UNOCC LD %>        100 |HTG USE % >        0 |assumed:              |assumed:                 |                       |                       |
|                      |% SUMMER  >        100 |MIN LOAD %>          0 |SUMMER LD%>      100 |HWS TEMP           140 |HWS TEMP             140 |                       |                       |
|                      |MIN LOAD %>          0 |% SUMMER  >        100 |                     |CWS TEMP            60 |CWS TEMP              60 |                       |                       |
|......................|.......................|.......................|.....................|.......................|.........................|.......................|                       |
|KW TOTAL  >         7 |TONS      >          9 |MBTU'S    >         64 |KW        >      1.8 |OCCUPANCY >         21 |OCCUPANCY >           16 |KW        >          2 |                       |
*******************************************************************************************************************************************


      USAGE                 UNITS NRG |SEPTEMBER  OCTOBER  NOVEMBER  DECEMBER   JANUARY   FEBRUARY    MARCH     APRIL      MAY      JUNE      JULY     AUGUST |TOTALS
*******************************************************************************************************************************************
                                      |
       LIGHTING             ELEC, KWH |   4,645     4,800     4,645     4,800     4,800     4,335     4,800     4,645     4,800     4,645     4,800     4,800 |   56513
        COOLING             ELEC, KWH |   4,627     2,694     1,451        94        42       672       545     2,232     3,575     5,256     6,857     5,798 |   33843
        HEATING             GAS, MBTU |       0         0     2,905    17,142    12,876     7,456     3,910         0         0         0         0         0 |   44289
 CLG/HTG ACCESSORIES        ELEC, KWH |   1,317     1,360     1,317     1,360     1,360     1,229     1,360     1,317     1,360     1,317     1,360     1,360 |   16018
   DOM. HW OFFICE           STEAM,MBTU|       0         0         0         0         0         0         0         0         0         0         0         0 |       0
   DOM. HW RESID.           STEAM,MBTU|       0         0         0         0         0         0         0         0         0         0         0         0 |       0
   MISCELLANEOUS A          ELEC, KWH |     783       809       783       809       809       731       809       783       809       783       809       809 |    9531
   MISCELLANEOUS B          GAS, MBTU |       0         0         0         0         0         0         0         0         0         0         0         0 |       0
*******************************************************************************************************************************************
EMERGENCY                   ELEC, KWH |  11,371     9,664     8,196     7,064     7,012     6,967     7,515     8,977    10,545    12,000    13,826    12,767 |  115905
SYS. NO.   8-2              GAS, MBTU |       0         0     2,905    17,142    12,876     7,456     3,910         0         0         0         0         0 |   44289
OCC. SQ FT      3200        STM, MBTU |       0         0         0         0         0         0         0         0         0         0         0         0 |       0
                            CHW, MBTU |       0         0         0         0         0         0         0         0         0         0         0         0 |       0
...........................................................................................................................................
                                                                                                                        TOTAL COMBINED BTU/SF  137,424
```

Figure 12 Input and output from simple spreadsheet simulation.

model a small community hospital that had a very large number of very different HVAC systems. This model was used to simulate each of the HVAC systems individually with the modeling accuracy results as shown in Figure 13. Considering the relatively small amount of engineering effort required for modeling, the results were excellent. Another appropriate and attractive use of this spreadsheet simulation tool would be as a first-order conservation assessment tool in the energy conservation sales process.

BUILDING SIMULATION AND ENERGY SERVICES

In approximately the last 10 years, a mini-industry has formed that has traditionally been referred to as the "energy services" industry. In the last year or two, the term "demand-side management" has also been applied to this business. What is essential to this industry is the business proposition of retrofitting an owner's building at essentially no initial cost to the owner (financing is provided by the energy services company or a third party) and guaranteeing in some fashion that the utility cost avoided by the project will equal or exceed the cost of the project (debt service plus any other ongoing costs such as project management or maintenance). Unfortunately for some projects done in this industry, the salespeople involved view the business proposition as simply a way to make their job easier and they exhort their technical staffs to generate savings calculations that would support a high dollar value for their projects. This is unfortunate, and even frightening, because savings figures so generated are difficult if not impossible to achieve in reality and, if the guarantee offered is reputable, it must then come into play to cover the savings shortfall that must necessarily occur. In a most dramatic example, one energy services company with which the author has worked had the unpleasant experience of having a sales engineer substitute his own savings calculations for those generated by the computer model. The result of this was a *guarantee of natural gas savings* on one project that actually *exceeded the natural gas consumption* of the building. Needless to say, management failed to properly consider the plausibility of such a proposition and approved the project for funding—and is presently funding the annual savings "shortfall" to the tune of more than $100,000 per year (not to mention destroying its relationship with the building owner). The use of cost-effective and accurate tools and methods of building simulation is an essential part of identifying and implementing successful energy services or demand-side management projects.

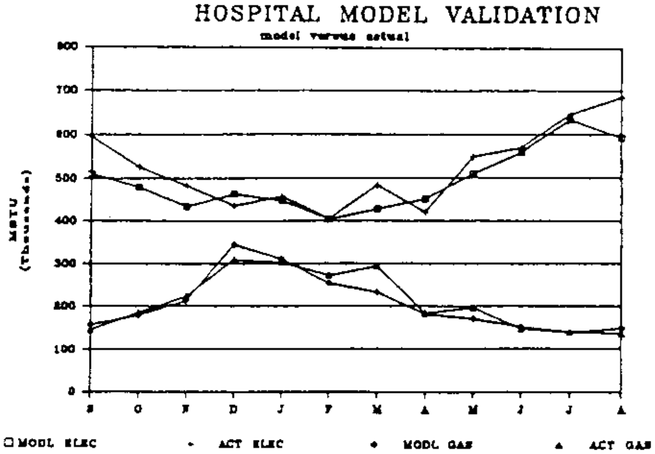


Figure 13 *Example of simple spreadsheet simulation results.*

CONCLUSION

While it is a fascinating and complex engineering tool, the fundamental value of computer simulation of buildings is that it forces a quality-enhancing step in the analytical process. This step is essentially a systematic confirmation of the engineer's knowledge of where and how energy is being used in a building. If the modeling step is done and done well, it is difficult to make "off target" recommendations for specific types of retrofits or "off target" estimates of savings. With such a high level of confidence established on the technical side of a project, the assessment and mitigation of project performance risk can rightly be performed on the financial side of the project evaluation, resulting in a very high probability of success for energy retrofit and demand-side management projects.

DISCUSSION

Fred Winkelmann, Group Leader, Lawrence Berkeley Laboratory, Berkeley, CA: What kind of improvements to building energy simulation programs would you recommend to help users avoid incorrect modeling of buildings?

J.P. Waltz: Our recommendation would be to concentrate effort in the direction of teaching computer simulation skills and procedures to users rather than concentrate on the programs themselves, as was the thrust of our paper. We suspect that 95% of the engineers in HVAC practice are incapable of using the programs that are currently available. Issues such as rigorous field surveys and output critiques are far more important than software features. At the same time, graphical output of simulation results (electrical demand profiles, thermal load profiles, etc.) would probably be very helpful. In addition, development of rule-of-thumb "help" tables for input variables (watts per square foot of lighting, etc.) would be very helpful for the novice user.