

A CALIBRATION METHODOLOGY FOR RETROFIT PROJECTS USING SHORT-TERM MONITORING AND DISAGGREGATED ENERGY USE DATA

Veronica I. Soebarto
Dept. of Architecture, Texas A&M Univ.
College Station, TX

Larry O. Degelman
Dept. of Architecture, Texas A&M Univ.
College Station, TX

ABSTRACT

This paper presents an improved methodology to calibrate energy simulation models to better represent the actual energy use breakdowns in existing buildings. The goal of this methodology is to help architects and engineers accurately determine the current energy use and identify any energy-related problems in the building before proposing the retrofit design solutions, without conducting long-term monitoring.

The methodology includes procedures to conduct systematic data collection, "on-off" tests to determine the power densities of the electrical loads, up to four weeks of building energy monitoring to derive the energy use profiles and temperature settings, and disaggregation of the measured energy use data. The procedures also utilize the monthly utility billing records and site weather data. The calibration to the measured data is done on both hourly and monthly basis.

The procedures are built into a computer program and integrated with previously developed simulation software. The user interface of the program includes guidelines to help the user decide which simulation input variable has to be altered in order to match the measured data. It also produces graphical outputs to help in visualizing the results, and several guidelines to help study different retrofit strategies after the model has been calibrated.

INTRODUCTION

Energy simulation programs are commonly used to predict the total energy use in a building that is being designed. Simulation programs are also used to calculate the energy savings of energy conservation retrofits to existing buildings. However, because real building operations are often different from those estimated, energy simulation tools alone are not able to accurately determine the actual building's energy use (3). In order for an energy simulation program to work properly in a retrofit project, it is necessary to calibrate the simulated data to the measured data so

that the model accurately predicts future energy savings.

For a number of years many research efforts have been dedicated to developing calibration procedures. However, several problems exist in the current procedures. First, no consensus standards have been published on calibration procedures that can be used on a wide variety of buildings (1). Some procedures recommend on-site hourly measurements of a building's energy use, while other procedures only require monthly energy use data, although calibrations to hourly data seem to produce the most accurate model (2, 8). Second, very few authors have accurately produced a complete and practical procedure for accomplishing this process, making it difficult for architects and engineers to follow the procedures. This issue is important as architects and engineers often need to propose retrofit designs accurately and quickly. Third, many of the previously developed procedures are time consuming and expensive. This becomes a problem for most small scale projects because many building owners and managers are not willing to invest the time and money to have a full audit of the building's energy use (13).

Therefore, there is a recognized need to develop accurate and practical calibration procedures to help building designers quickly identify energy use problems in existing buildings before retrofit designs will be analyzed. This paper discusses a thorough yet simple methodology that can be used by architects and engineers to determine the energy end-use of an existing building. The method makes use of data that can be easily obtained and collected; they are monthly utility records of the building, two to four weeks of monitored energy data, short measurement results, on-off test data, and building description data from site observations. These data are used to disaggregate the total energy use into the components of heating, cooling, fan motors, lighting, receptacles, and domestic hot water, and to calibrate the simulation model.

METHODOLOGY

The methodology includes the procedures: (a) to collect various building, energy and weather data, (b) to define the non-weather dependent load densities through the on-off tests, and (c) to develop the end-use profiles through two-to-four weeks of energy monitoring. The data collected using these procedures are then input to an hourly energy simulation program previously developed in the Department of Architecture, Texas A&M University (4, 5, 14). The program will compare the disaggregated energy use from the simulation to the disaggregated measured data, reporting which components of the simulated results that do not match the measured data. The knowledge database of the program will then assist the user to change certain input in order to match the simulated result with the measured data. These procedures are summarized and shown in Figure 1.

These procedures were developed using an office and classroom building (Zachry Engineering Center) located on the campus of Texas A&M University (Figure 2). The data collection and on-off tests were conducted in Summer 1995.

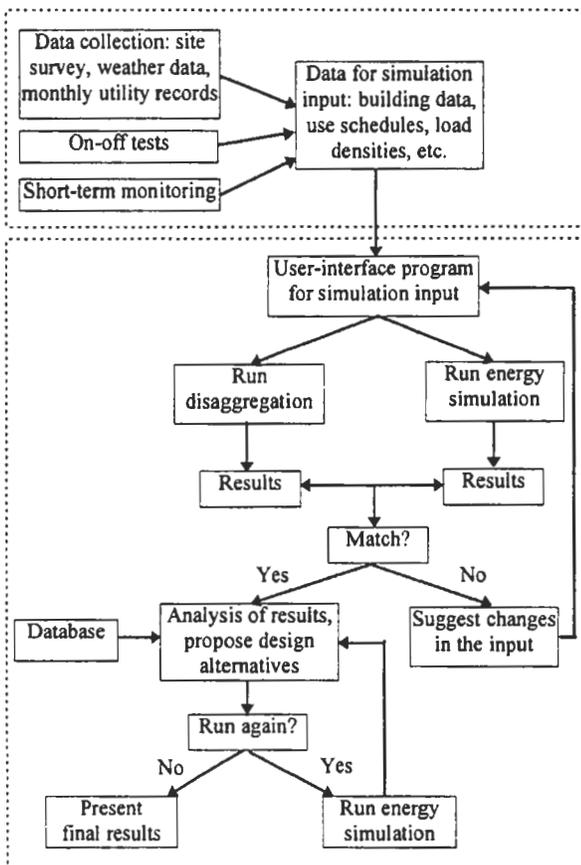


Figure 1. Data collection and calibration procedures

DATA COLLECTION PROCEDURE

The required building and related data include (a) building physical data, (b) building HVAC data, (c) building operation data, (d) weather data, and (e) monthly utility records.

Building Physical Data

The building physical data were obtained from the architectural drawings and site survey. These data can be categorized into several components. First was the exterior, which included the building orientation, surrounding buildings, trees, other structures, shading conditions, and ground surfaces surrounding the building. Second was the building envelope, which included: wall/roof assemblies and window/skylight materials (both of which determine the thermal properties of the envelope), shading devices on the exterior and interior surfaces, and the dimensions of the building, walls, windows, and roof. Third was the building interior, which included the floor plans, the function of each space, ceiling heights, lighting and receptacle types, and lighting levels during day and night.

A standardized survey form was used to maintain consistent data collection from project to project. Photographs were also required in this step. The period required for the data collection obviously depends on the size and complicity of the building. For the test building, the data collection was done in 8 hours.

Building HVAC data

The building HVAC data were obtained by reading the name plates of the HVAC equipment, directly measuring several parameters of the equipment, or interviewing the building operators. The data collected included the HVAC system type(s), efficiencies, and power(s); fan motor horsepower(s) and air supply rate(s).



Figure 2. The Engineering Center

Building operation data

The building operation data were obtained through brief observations, measurements, and interviews with the building operators or managers. These data included peak levels and 24-hour schedules for occupancy, lighting, receptacles, ventilation, fan motors, and domestic hot water heating. To determine the lighting and receptacle loads, the observations were conducted during the day and night. This included counting the number of fixtures and equipment that were on or off during in the day and night time. The observations in the test building took about 4 hours during the day and 2 hours at night.

The space temperature(s) were obtained by directly measuring the temperatures inside the space. These measurement were done during the day and night. To monitor the temperature in different spaces for a 24-hour period, we used a portable temperature logger. The data were later downloaded to a personal computer for the data analysis.

It is important to recognize that the designer should not totally rely on the information obtained from building operators, because often the actual operating schedules are different from what were declared in the interview (3). The methods to determine the operating schedules will be discussed under "on-off tests" and "short-term monitoring."

Weather Data

The weather data for the period when the simulation would be calibrated were also obtained. The data included dry bulb temperatures, wet bulb temperatures or relative humidity, wind speeds, and solar radiation. These data were obtained from the nearby weather station and the Energy Systems Laboratory at Texas A&M University.

Because usually the nearby weather station, such as the airport, only measures the global solar radiation, a model is required to convert the global solar radiation into the direct and diffuse components. The method used in this work was based on Liu and Jordan (11). This model has been incorporated in the weather simulation program used in this work (4). Therefore, the user only needs to provide the weather data in the following format: date of the year, hour of the day, dry bulb temperature, wet bulb temperature, global solar radiation, and wind speed.

Monthly Utility Records.

The monthly utility records were also used as one means to calibrate the simulation model. These

data can usually be obtained from the local utility company. All utility records for the fuel types used in the building should be collected. These may include the electricity, gas, domestic hot water, chilled and hot water for space heating and cooling, or steam for space and water heating. At least 12 contiguous months of data in a single calendar year should be obtained. Because the ZEC Building did not have utility bills, however, the monthly data were gathered from the hourly measured data, monitored by the Energy Systems Laboratory.

ON-OFF TEST

Norford et al. (12) found in their work that the predicted annual energy use before the calibration was found to be one-half of the actual energy use. Most of the discrepancy was due to the input for the occupant use of lighting and equipment, including unanticipated schedules and low predicted loads. These contributed to 64% of the discrepancy. Excessive HVAC operations were found to contribute 24% of the discrepancy.

To minimize this discrepancy, therefore, it is necessary to obtain the actual energy use for all electrical loads. The site survey, as explained above, can provide this information. However, this method has some drawbacks. First, counting all lighting fixtures and equipment (receptacles) can be time consuming, depending on the size of the building. Second, although the lighting plans and schedules can be used to estimate the number of light fixtures and determine the total loads, often the current installed lighting fixtures are different than that shown on the drawings. Third, often the lighting fixtures are located in hidden or unreachable places, making it difficult to determine the lighting type and wattage when no other information is available.

These problems can be solved by conducting the on-off test. The objective of the on-off test is to isolate each type of electrical load in the building so the loads for lighting, receptacles, and fan motors can be determined without conducting a long term monitoring effort. The value obtained for each type of load, usually in kilowatts, will become the peak value. Then, by converting this value to watts and dividing it by the floor area, the power density of each type can be determined and can later be used for the input to the simulation program.

On-off test procedure overview

In this test, the lights, receptacles, fan motors, and all other electrical loads were turned on and off

in a predetermined pattern. The electrical consumption during the tests was recorded by a data logger connected to the electrical panels. Because this logger can be connected to a PC either through a direct serial connection or through a modem line, the data during the tests was monitored and later downloaded to the PC. The data logger used in the test building was the Synergistics data logger (6, 15), which has been installed for monitoring purposes since 1990. Other types of data logger are obviously acceptable as long as they can monitor power.

To minimize the time to turn the lights and receptacles on and off, lights and receptacles were turned on before the test. Then, turning them on and off during the test were controlled from the circuit breakers. However, if the building is small, or if the load of a particular space is sought, it is better to turn the light and receptacles on and off using the switches in each space.

Planning the test

Since every building is unique, the steps for the on-off test were planned together with the building operators. Two weeks before conducting the test, the building occupants were notified despite the fact that the test was conducted while the building was unoccupied. The building security personnel was also notified.

Before the test, the lights and receptacles to be turned on and off were grouped into several zones. For any building, this division depends on how the building will be zoned in the simulation program. Eight people were also required to help conducting the test, each was responsible for one or more zones. However, for any building, the number of people required depends on the size of the building and how the building is zoned. Other equipment needed were several walkie-talkies to ease the communication during the test, and flash lights to be the temporary light source since the building became dark during certain periods in the test.

Steps in the test

After all lights, receptacles and other equipment were turned on, the test was started. The data logger recorded this condition for at least 5 minutes. Then step-by-step, all lights and equipment were turned off through the circuit breakers. The logger recorded the data in each step for at least 5 minutes.

The next step was to turn off all outdoor lights. Then all indoor lights were turned off. If possible, the next step should be to turn off all receptacles. However, since we were not allowed to turn off the receptacles, this step was skipped. Then, the fan motors of the AHU's were turned off. In this building, the AHU's were the last equipment to be turned off because the temperature in the building could rise quickly without the air-conditioning system. At this time, if no other loads existed, the reading should have been zero. However, the logger still recorded some "other" loads, which included emergency lights, elevators, and pumps. The logger recorded this condition for at least 5 minutes.

The next step was to turn on all fan motors, and after the reading was stable, the difference between the current and previous reading became the fan motor loads. If turning on the receptacles had been possible, the next step would have been to turn on the receptacles. For any building, if the receptacle load in each zone is sought, the receptacles should be turned on zone-by-zone; thus, the difference between each step is the receptacle load for that zone. Next was to turn on the lights zone by zone to determine the lighting load in every zone. After that, the outdoor lights were then turned on. Finally, some lights were turned off to go back to the condition before the test.

Sample result

Figures 3 and 4 show the data recorded during the on-off test. It can be seen that the test was able to clearly separate the lighting load in every floor. However, because the building manager did not allow the receptacles to be turned off, the test was not able to separate the receptacle loads on every floor.

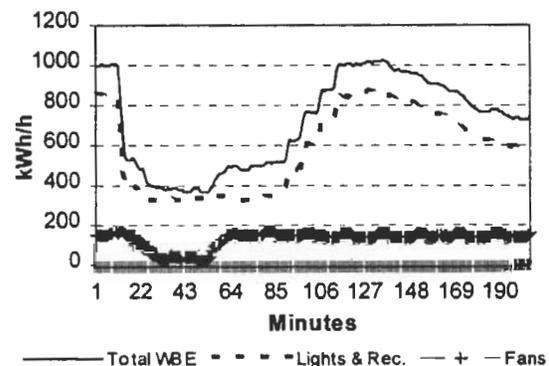


Figure 3. Electrical consumption in the test building during on-off tests

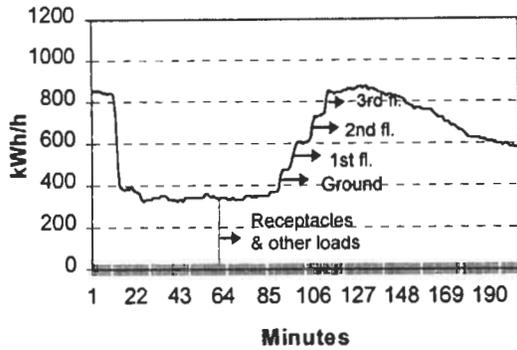


Figure 4. Lighting and receptacle loads

The lighting loads recorded during the test were then compared to the estimated lighting loads from site survey. As shown in Table 1, both methods gave close results; however, the on-off test provided more accurate measurements. From the survey, for example, the lighting load on the ground floor was estimated by counting the number of light fixtures that were on, multiplying it by the wattage of each fixture, and then taking the ballast factor, which was 0.25, into account. The result was 115.98 kW. The on-off test showed that the lighting load on the ground floor was actually 113.95 kW, showing that the actual ballast factor was not exactly 0.25.

The lighting load on each floor obtained from this test was then divided by the floor area, yielding the power density of the lighting on that floor, which was later be used for the input to the simulation.

Table 1. Comparison of on-off test and survey results

Floor	On-off test results (kW)	Estimated from Survey (kW)	% diff.
Ground	113.95	115.98	1.78
First	128.55	129.41	0.67
Second	120.8	126.81	4.97
Third	113.20	114.56	1.20

SHORT-TERM MONITORING

As shown by Norford et al. (12), besides the lighting and receptacle loads, unanticipated use schedules contribute to most of the discrepancy be-

tween the simulation results and measured data. To develop more accurate use profiles, an hourly monitoring is required. Several methods have been developed, including the proxy method to develop electric load factor-occupancy load factor day-type profiles (ELF-OLF) by Haberl and Komor (7). This method uses two weeks of monitored data (2, 8), and the hourly data from a full six-month data set (9).

Based on objectives of the methodology presented in this paper, the recommended procedure is to use two weeks of monitored data to develop the use profiles. The hourly monitored data from the whole month will later be used to calibrate the simulation results.

The 24-hour use profiles developed using two weeks of hourly monitored data were compared to those using four weeks of hourly monitored data. The results showed that if the building has the same occupancy schedule in the entire month (no long holidays), both data will yield similar profiles (Figure 5). Thus, using two weeks of monitored data is suitable for developing the use profiles. The authors also tested the profiles developed from a particular month with those developed from other months in the year. Again, the result showed that as long as the building has the same operating schedules and does not have long holidays, two weeks of monitored data from one month is adequate to develop the use profiles (Figure 6). However, if it is known that the building has several occupancy schedules, such as summer, Christmas holiday, and regular schedules, but the monitoring can only be done in one season, then the profiles for the other seasons should be estimated based on the interview statements made about changes in occupancy.

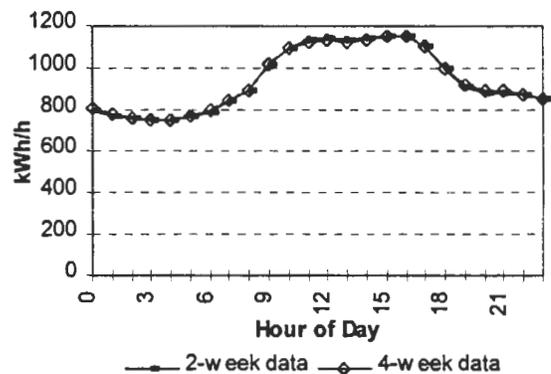


Figure 5. Daily use profiles from 2-week and 4-week measurements

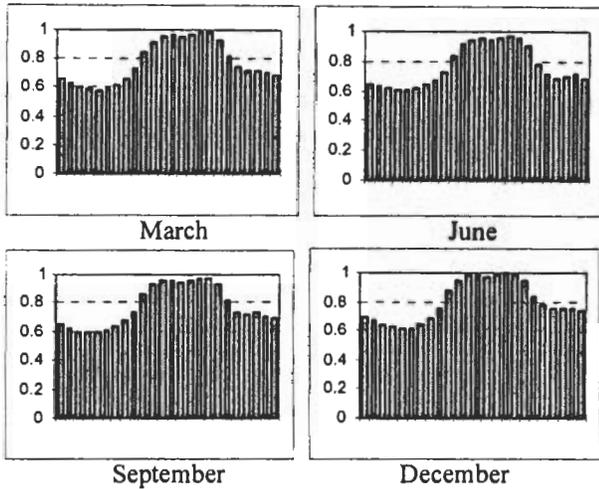


Figure 6. 24-hour workday lighting profiles in March, June, September, December in ZEC Bldg.

Procedure to develop 24-hour use profiles

To develop the 24-hour use profiles for the whole-building electric, lighting, receptacles, and fan motors, the loads should be monitored separately whenever possible. However, it is more difficult to separate the monitoring of the receptacles and from the lighting in a large building because often they share power from the same electrical panel. In this case, the result from the on-off test can be used as the weighting factors to separate the receptacles from the lighting.

The procedure to develop a 24-hour use profile of any electrical load is as the following. The corresponding data were downloaded from the data logger. These data were in a columnar format. Then using the "cols.com" program (6), the decimal date and the measured data were separated from the entire measured data. Using a program called "colrow3d" (6), these data were then converted into a 24-hour format with the hour of the day as the column headers and the dates as the rows (Table 2).

The next step was to group the data into workdays and weekend using a spreadsheet program. For every hour, the measured data from the workdays were averaged to get the average load for that hour (Table 3). The use profile, with values from 0 to 1, can then be developed by dividing the value of each hour by the peak value in the 24-hour period. The same procedure was done for the weekends.

Table 2. Sample of decimal date and whole building electric data on August 22, 1994

5712	752.563
5712.042	727.448
5712.083	724.057
5712.125	723.806
5712.167	722.802

Decimal Date
WBE data

Table 3. Sample of data in 24-hour format to develop use profiles

	1	233	0	1	2 ... 24
Sat	6	238	722.2	721.5	711.9
Sun	0	239	730	721.3	715.6
Sat	6	245	800.4	749.8	741.1
Sun	0	246	764	752.6	743.6
Ave			754.15	736.3	728.1
Tue	2	234	752.6	727.4	724.1
Wed	3	235	764	752.8	736.4
Thu	4	236	759.5	753.6	746
Fri	5	237	732	719.2	708.5

SIMULATION, DISAGGREGATION AND CALIBRATION

The building parameters and the weather data collected using the above procedures were then input to the ENER-WIN program (4, 5, 14). This program produces monthly summaries of each component's energy use and total peak demands as well as a disaggregated summary of total annual energy. Hourly output of energy consumption is also available.

The comparison of the simulated results to the measured data was done in two ways. First, it used the two-to-four weeks monitored data to calibrate the hourly simulation results for the same period. The required measured data were only the date, hour of the day, and the hourly energy data. The calibration included a comparison to the disaggregated values of the total energy (space heating, space cooling, fan motors, lighting, receptacles, and domestic hot water); the daily peaks; the 24-hour profile and the hourly values of the whole building electric, lighting, receptacles, heating and cooling energy.

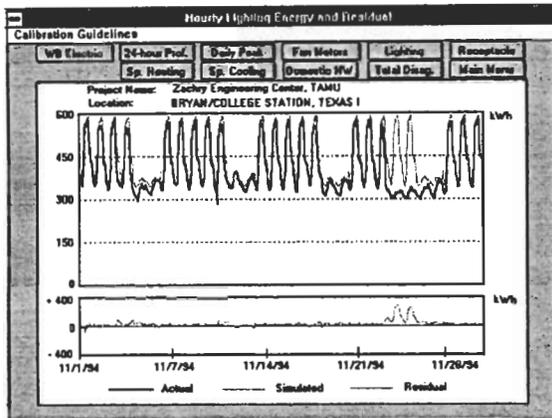


Figure 7. Comparisons of simulated and hourly measured lighting energy

Figure 7 shows a comparison of hourly measured to simulated lighting energy and also the residuals. If the measured data do not separate the lighting and receptacle loads, the lighting will be separated from the receptacles the lighting and power densities in each zone by applying weighting factors.

The second way to calibrate the simulation was to compare the monthly simulated end-uses to the disaggregated monthly utility records. This was to calibrate the simulation for the months when the hourly measured data were not provided. These monthly calibrations included comparing the space heating, space cooling, fan motor, lighting, receptacle, and domestic water heating energies. Other calibrations included comparing the simulated monthly whole building electric and peaks to those from the utility records, and the simulated disaggregated annual energy use to the disaggregated annual energy use from the utility records.

Before conducting the monthly calibrations, the monthly and annual energy uses from the utility records were disaggregated into space heating, space cooling, fan motors, lighting, receptacles and domestic water heating. In general, this process depends on the type of energy use for space heating, space cooling and domestic water heating, and on the operation of the fan motors.

Gas heated and electrically cooled building

If the building is heated with gas, first the "base load" can be calculated. They are the lighting and receptacle loads. The energy is calculated using the load densities, floor area, and the number of operating hours defined by the schedules or use profiles. If the fans operate according to a fixed schedule, the

base load should also include the fan energy. The fan energy is calculated by using the fan horsepower or wattage and the operating hours. The remaining electrical energy is used for space cooling. Space cooling includes chiller and auxiliary equipment which are the chilled and condenser pumps but not the air handling units.

If the fans only run when there is a load, the process is rather complicated. At this moment, we are still working on this issue using the following approach. First, the periods when the fans are running should be determined using other tools that can determine the change point temperature(s) when the building switches to the cooling or heating mode (10). This method only requires utility records and outdoor dry bulb temperature from several previous months, and uses regression analysis to determine the change point temperature(s). If the outdoor dry bulb temperature is less than the lower change point temperature, it is assumed that the building is in the heating mode and the fans are running. If the temperature is above the higher change point temperature, the building is in the cooling mode, thus the fans are also running. The fans are assumed to be off when the outdoor dry bulb temperature is between the two change point temperatures. Then, the power of and the number of hours the fans and the compressors are running will be used as the weighting factors to separate the remaining electrical energy into the fan energy and cooling energy.

To determine the space heating energy, first the domestic hot water energy is calculated since usually the water is also heated with gas. The amount of water heating energy is calculated using the data on the number of amount of daily occupant use, the number of people, the average ground temperature for each day, and the assumed efficiency of the water heater. The remaining gas use is then allocated for space heating energy.

Electrically heated and cooled building

If the building is both heated and cooled using electricity, the procedure is further complicated. First, the lighting and receptacle energies are calculated. Then depending on the type of the domestic water heating system, the water heating energy can be calculated using the same procedure as above, except the heating value for electricity should be used. If the fan operations are fixed by schedules, the fan energy can also be calculated. The remaining will be allocated for space heating and space cooling energy.

If the fans run only when there is a load, the remaining electricity is shared between the fan, space heating and space cooling energy. Thus, there are three weighting factors -- one each for fans, space heating and space cooling. Each is based on the power of the respective equipment and the number of hours the equipment is operating. We are also still working on this issue using the same approach as mentioned above.

The actual monthly electrical use of the fans, space heating and space cooling can then be calculated by multiplying the corresponding weighting factor with the remaining kWh in each month. Equations 1 to 7 show the procedure to calculate the weighting factors. The motor kW values may be estimated by multiplying the horse power (HP) by 0.75.

$$\text{Fan kWh} = \left(\frac{\text{Tot. hrs of heating + cooling}}{\text{Total fan kW}} \right) \times \text{Total kWh} \quad \text{Eq. (1)}$$

$$\text{Heat kWh} = \text{Tot. hrs of heating} \times \text{Heater kW} \quad \text{Eq. (2)}$$

$$\text{Cool kWh} = \text{Tot. hrs of cooling} \times \text{Chiller kW} \quad \text{Eq. (3)}$$

$$\text{Total kWh} = \text{Fan kWh} + \text{Heat kWh} + \text{Cool kWh} \quad \text{Eq. (4)}$$

Weighting Factors:

$$\text{Fan WF} = \frac{\text{Fan kWh}}{\text{Fan kWh} + \text{Heat kWh} + \text{Cool kWh}} \quad \text{Eq. (5)}$$

$$\text{Heat WF} = \frac{\text{Heat kWh}}{\text{Fan kWh} + \text{Heat kWh} + \text{Cool kWh}} \quad \text{Eq. (6)}$$

$$\text{Cool WF} = \frac{\text{Cool kWh}}{\text{Fan kWh} + \text{Heat kWh} + \text{Cool kWh}} \quad \text{Eq. (7)}$$

Space heating and cooling with central water system.

If the space heating uses central hot water system and space cooling is done with central chilled water system, the disaggregation is much simpler. For the electrical loads, the lighting and receptacle energies can be calculated, and the remaining electrical energy is used for the fan motors. It should be noted, however, that the monthly electric input to the program should only consist of the energy for lighting, recep-

tacles, and fan motors. If outdoor lighting is included, the monthly electrical consumption data should be prorated using the values obtained from the on-off test. The heating and cooling energy can be directly determined using the monthly data of the hot water and chilled water consumption. This approach was applied in our work since the test building uses central chilled water for space cooling and hot water for heating. For this building, the chilled water pumps were represented as the receptacle load in the unconditioned space.

Monthly Disaggregation Validation

The method to disaggregate energy use using the monthly utility data only was tested by comparing the disaggregated results to those using the measured hourly data. The fan motors were measured separately from the whole-building electric. Figure 8 shows these comparison of the disaggregated total energy for November 1994. The results show that the differences between the disaggregated energy use based the monthly utility records and measured data are only 0.3% for the fan energy and 0.08% for lights and receptacles.

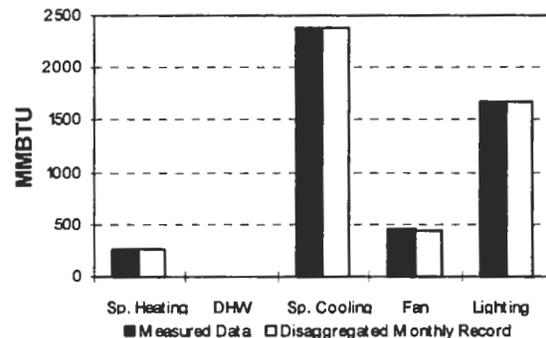


Figure 8. Comparison of disaggregated energy use using monthly records and measured hourly data

CALIBRATION GUIDELINES

Figure 9 shows the comparisons of the monthly whole building energies from the simulation model and utility records. The comparison of the monthly cooling energies is shown in Figure 10. Once the simulation results were compared to the measured data, either by using hourly data or monthly utility records, the program detected and reported which of the results fell beyond the predetermined normative values. The acceptable discrepancies are the followings: 10% for annual values, 10% for peaks, 10% for total electric, lighting, receptacles, and fans on a monthly basis, 15% for space heating and space cooling, and 15% for hourly values.

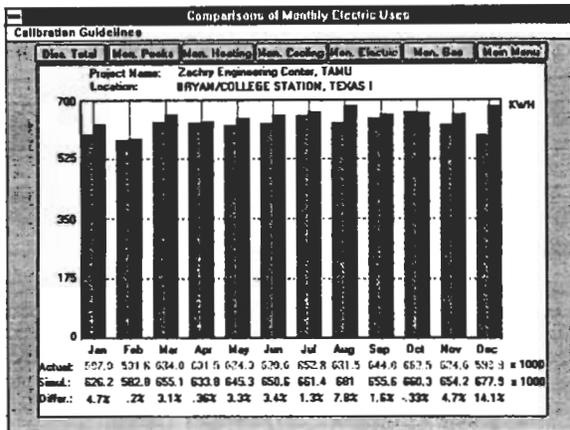


Figure 9. Comparison of simulated and measured whole building electricity

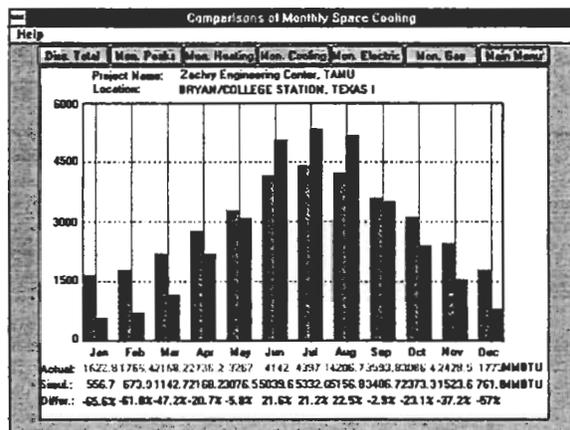


Figure 10. Comparison of simulated and actual monthly cooling energy

To calibrate the heating energy:

1. Make sure the thermostat settings match the real thermostat setting in the building. If no adequate data are available, do the following: if the simulated heating energy is higher than the measured data, lower the thermostat settings in the winter. Do the opposite for the summer.
2. Adjust the efficiency of the heating system.
3. Check the ventilation rate(s). If no data are available, try to increase the ventilation rate if the simulated heating energy in the winter is lower than the measured data, or visa versa. Also adjust the ventilation schedule(s).
4. Adjust the infiltration rate. If the simulated heating energy is lower than the measured data, increase the infiltration rate, or visa versa. If no adequate data are available, estimate the infiltration rate using the following rule of thumb:

- tight skin construction: 0.2 - 0.6 ACH
- medium skin construction: 0.6 - 1.0 ACH
- loose skin construction: 1.0 - 2.0 ACH

Figure 11. Sample of calibration guidelines

The program then presented a data base which help re-checking and adjusting certain simulation input. Figure 11 shows an example of this guideline. After changing certain inputs and rerunning the simulation program, the results were once again compared to the measured data. The iterations continued until the simulation results fell within the acceptable ranges.

IMPACTS ON ARCHITECTS AND ENGINEERS

The main objective of this work is to help architects and engineers in calibrating the energy simulation model. Only after the simulation model represents the actual condition of the building, can the model be used to study different retrofit design alternatives.

At the present time, this program is being developed to provide a guideline to the user in the retrofit design process. The program will be supported with a database that will assist the user in analyzing a retrofit design, based on the calibrated simulation results. We are also working on developing the disaggregation and calibration methods when only hourly whole-building electric data are available without any sub-metered data. Overall, it is expected that the methodology and the program will help architects and engineers to do a retrofit project in a more accurate way by performing modest measurements that can be handled quickly.

SUMMARY

This work has shown that when long-term monitoring is a burden, the current energy use of a building can still be predicted with acceptable accuracy with an energy simulation program using only monthly utility records and two-to-four weeks of measured data. This is possible if the input to the simulation model is derived from a careful, yet simple procedure.

The data collection procedures help the architects or engineers to collect the necessary data. The on-off test has been shown to be a quick and simple procedure to obtain accurate electrical loads and power densities. The short-term monitored data provide valuable information that can be used either to develop use profiles, calibrate the hourly simulated results, or check the accuracy of the disaggregated values based only on the monthly utility records.

The procedures attached to the simulation program will help the architect and engineer to visualize the calibration process and results, guide the users in adjusting the corresponding parameters, and finally help them in analyzing the retrofit design alternatives once the simulation model contains a good representation of the actual building.

ACKNOWLEDGMENTS

This work is funded through the Energy Resource Program from the Center for Energy and Mineral Resources at Texas A&M University, College Station, Texas. The authors also wish to acknowledge Professor Jeff Haberl, Ph.D, the Energy Systems Laboratory and the College of Engineering at Texas A&M University in conducting the on-off test and the energy monitoring.

REFERENCES

1. Bou-Saada, T.E. 1994. "An improved procedure for developing a calibrated hourly simulation model of an electrically heated and cooled commercial building", A Thesis for Master of Science, Department of Mechanical Engineering, Texas A&M University, Dec., 255 pp.
2. Bronson, D.J., Hinchey, S.B., Haberl, J.S., O'Neal, D.L. 1992. "A procedure for calibrating the DOE-2 simulation program to non-weather-dependent measured loads", ASHRAE Transactions 98(1):636-652.
3. Burt Hill Koss Rittelmann Assoc., Min Kantrowitz Assoc. 1987. Commercial Building Design: Integrating Climate, Comfort, and Cost. New York: Van Nostrand Reinhold, p. 45.
4. Degelman L.O. 1991. "A statistically-based hourly weather data generator for driving energy simulation and equipment design software for buildings", Proc. 2nd World Congress on Technology for Improving the Energy Use, Comfort, and Economics of Buildings Worldwide, International Building Performance Simulation Assoc. (IBPSA), Nice, Sophia-Antipolis, FRANCE, August 20-22.
5. Degelman, L.O. 1990. "ENERCALC: A weather and building energy simulation model using fast hour-by-hour algorithms", Proc. 4th. National Conference on Microcomputer Application. in Energy, Univ. of Arizona, Tuscon, May.
6. Haberl, J., Claridge, D. 1992. LoanSTAR Monitoring Workbook, Texas LoanSTAR Monitoring Program, Energy System Laboratory, Texas A&M University, December.
7. Haberl, J., Komor, P. 1990. "Improving commercial building energy audits: How annual and monthly consumption data can help", ASHRAE Journal, August.
8. Kaplan, M.B., Jones, B., Jansen, J. 1990. "DOE-2.1C model calibration with monitored end-use data", Proc. ACEEE 1990 Summer Study on Energy Efficient Buildings 10: 10.115-10.125, Washington, DC: American Council for an Energy Efficient Economy.
9. Katipamula, S., Haberl, J. 1991. "A methodology to identify diurnal load shapes for non-weather-dependent electric end-uses", Solar Engineering 1991: Proceedings of the ASME-JSES-JSME International Solar Energy Conference, Reno, Nevada, March, pp. 457-467.
10. Kissock, K., Wu, X., Sparks, R., Claridge, D., Mahoney, J., and Haberl, J.S. 1994. Emodel, Energy Systems Laboratory, Texas A&M University.
11. Liu, Benjamin Y.H. and Jordan, Richard C. 1960. "The Interrelationship and Characteristic Distribution of Direct, Diffuse and Total Solar Radiation", Solar Energy, Vol IV, No. 3, July 1960.
12. Norford, L.K., Socolow, R.H., Hsieh, E.H., Spadaro, G.V. 1994. "Two-to-one disparity between measured and predicted performance of a 'low-energy' office buildings: Insight from a reconciliation based on the DOE-2 model", Energy and Building 21(1994): 121-131.
13. Reynolds, C., Komor, P., and Fels, M. 1990. "Using Monthly Billing Data to Find Energy Efficiency Opportunities in Small Commercial Buildings", Proc. ACEEE 1990 Summer Study on Energy Efficient Buildings, v. 10:10.221-10.231.
14. Soebarto, V. I. and L. O. Degelman. 1995. "An Interactive Energy Design and Simulation Tool for Building Designers", Proc. Building Simulation '95, Madison, WI, The International Building Performance Simulation Association (IBPSA), 14-16 Aug.
15. Synergistic. 1990. Software, Installation, and technical Specifications for the Model C180 Survey Meter/Recorder. 5725 Bundy Rd., New Orleans, LA 70127.