More Data Is Better, But How Much Is Enough for Impact Evaluations?

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The use of building energy simulation models in the engineering analysis of the savings from conservation or energy efficiency measures is a widely-accepted procedure in the evaluations of the gross impacts of DSM programs[1]. Also, simulation models are used to disaggregate whole-building loads into end-use components[2]. The purpose of this study was to evaluate how well energy use predicted with building energy simulation models compares with energy use measured by end-use metered data. Additionally, this study was designed to demonstrate how predicted energy use is affected by different level of data availability.

In order to demonstrate the impact that the use of data at different resolution levels have on the estimation of HVAC energy use, the following levels of resolution were defined:

- Level (1) Detailed building characteristics data collected on-site.
- Level (2) Monthly energy and peak demand billing information with level (1) data.
- Level (3) Inspection of working condition of HVAC equipment with level (2) data.
- Level (4) Whole-building hourly data with level (3) data.
- Level (5) End-use monitoring data for major non-conditioning loads with level (4) data.

The results of the analysis indicate that a combination of detailed audit data with monthly utility bills provides reasonable accuracy for determination of annual consumption of HVAC systems. However, for a better understanding of HVAC load shapes, whole-building hourly load profile data (e.g., utilities' load research data) can significantly improve the accuracy.

Introduction

The question of how much data are necessary to adequately simulate a building and obtain reasonable end-use load shapes requires defining what is "reasonable." This reasonableness changes, depending on the objectives for which the simulation results are being used. The objectives could include a good understanding of annual energy use, of monthly or annual peak demand, or of daily load shapes. The objective of this study was to evaluate the improvement of the simulation results for annual energy use and average daily load shapes. Another study[3] has used other approaches to develop load shapes; however, this study is concentrated on building simulations developed only on engineering principles.

The study and the resulting paper are based on results of a combination of several research projects conducted for the Southern California Edison Company (SCE). These include an impact evaluation of commercial hardware rebate project,[4] a commercial building commissioning project, and an end-use metering project.[5] The type of data that each one of these projects provided for the analysis is described below. An overview of the analysis approach is given in Figure 1.

The analysis was focused on five levels of data. Specific definitions for each level are as follows:

First   On-site data collection was conducted to obtain data detailed enough for DOE-2 simulation. Building operation information was obtained through interviews with the building managers/operators. These data were used to develop a DOE-2 input (BDL) file using the pre-processor (a BDL generator).

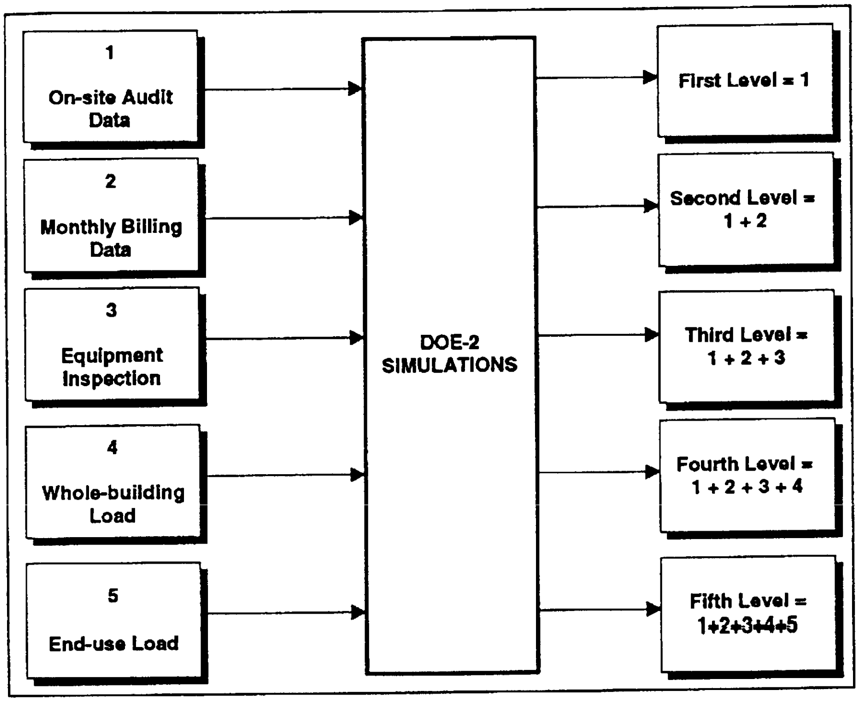

Figure 1. Analysis Approach

Second Building monthly billing data, including kWh and kW, were available to reconcile the results obtained from the DOE-2 simulations.

Third An additional inspection of the site was conducted to check the operation of the HVAC equipment (i.e., condition of filters, time clocks, economizers, mixed air dampers, etc.) This information refined the data obtained from the walk-through audit performed in the first step.

Fourth Whole-building hourly energy use data were available. These data were used to further refine the operations schedule of the equipment, particularly during the building's non-operational periods.

Fifth End-use load shapes were available from an end-use monitoring project for the major non-conditioning equipment, mainly lighting for all six buildings.

Methodology

Under the impact evaluation project, a sample of buildings that had received a rebate from the utility were visited, and detailed on-site data were collected. The level of detail was sufficient to develop a DOE-2 input file (BDL) using a DOE-2 pre-processor developed by ADM. The pre-processor describes the geometrical layout of a building by defining walls, windows, roofs, floors, basements; providing operating schedules for HVAC, lighting, equipment and other internal loads; and developing thermal zones within each building. The output of the pre-processor is a complete BDL file that describes the building for simulation with DOE-2. The buildings under this project were then simulated using DOE-2.lE. This project provided two initial sets of data used for the analysis in this paper: the collected data and a first set of DOE-2 estimates of HVAC energy use.

The results of the simulations were then compared with actual monthly bills. Based on this comparison, operational schedules were modified to reconcile the DOE-2 estimation more closely with the billing information. The results of the comparison provided the first and second level of results which were used in the analysis reported in this paper.

The objective of the second project, which is ongoing, is to address the potential for energy savings from recommissioning existing commercial buildings. As part of this evaluation, a subset of the building sites visited in the first study were revisited. During this second visit, HVAC operation and conditions were further investigated. Panels from the HVAC equipment were removed to identify filter conditions, loose belts, sensors operations, damper controls and other failures that could cause the equipment not to operate at the intended design. The information obtained from this revisit were then used to alter the original BDL, and the modified BDL files were re-run through DOE-2. The results of this simulation provided estimated HVAC energy for the third level.

A commercial building end-use monitoring project that has been ongoing for the past several years provided the necessary data and information for the fourth and fifth levels. Data on whole building loads that were collected at fifteen-minute intervals were aggregated to develop hourly load profiles, which were then averaged for each season. Most utilities have load research data that could be used for verifying simulation results. These types of data provide valuable insight to the operation of the building equipment, particularly during the time that the auditor is not in the building. Initial simulations of the operation of equipment during these periods are based on the information obtained during the interview of the building manager/operator. By using the whole-building load profiles, the schedules in the original data file were changed to reflect the additional information on operations during those periods of time not observed by the auditor.

In some cases, there was very little or no change in the schedule. In other cases, the new data only provided a shift in “on” or “off” time of an end-use or equipment. The results of the simulation using the changes resulting from the review of the whole building load shapes provided the HVAC energy use for the fourth level.

The results for the fifth level were obtained by using lighting profile data collected through end-use monitoring and re-simulating the buildings in place of estimated lighting profiles.

Building Specifications

The six buildings selected for this study had data for all five levels of analysis, including HVAC monitored data. There were three office buildings and three retail stores, all located in Southern California. The description of the buildings is provided Table 1.

Results

Table 2 compares total building end-use intensities (EUIs) and HVAC end-use intensities for each test building and level of data. These statistics reflect the accuracy with which each analytical level estimates energy consumption. Table 3 lists the root mean squared errors (RMSE) for the

Table 1. Building Characteristics

Building Name	Office 1	Office 2	Office 3	Retail 1	Retail 2	Retail 3
Floor Area (SqFt)	15,930	45,677	35,327	26,526	61,182	23,116
Weekday Occupancy Schedule	7:30am - 4:30pm	8am - 5pm	7am - 6pm	10am - 6pm	9am - 9pm	9am - 9pm
Saturday Occupancy Schedule	closed	9am - noon	10am - 2pm	10am - 6pm	9am - 9pm	9am - 9pm
Sunday Occupancy Schedule	closed	closed	closed	noon - 5pm	9am - 7pm	10am - 7pm
HVAC Control	Timeclock	Timeclock	Prog. Controller	Timeclock	EMS	Prog. Timeclock
Weekday HVAC Schedule	6am - 5pm	4am - 10pm	6:30am - 6pm	6am - 6pm	4am - 11pm	7am - 11pm
Saturday HVAC Schedule	as needed	as needed	10am - 2pm	6am - 6pm	4am - 11pm	7am - 11pm
Sunday HVAC Schedule	as needed	as needed	off	6am - 6pm	4am - 11pm	7am - 11pm
Heating Setpoints	72/off	68/off	71/off	70/60	70/off	65/off
Cooling Setpoints	76/off	72/off	75/off	75/82	74/off	70/off
Air handling system type *	DDS/VAV	DDS/MZS/SZS	DDS	PSZ	SZS	SZS
Cooling Plant	Recip. Chillers	Recip. Chillers	Recip. Chiller	DX	Recip. Chillers	Recip. Chiller
Cooling Capacity (Tons)	145	85 and 15	60	64	140	48
Cooling COP	3.2	2.87 and 3.64	3.5	2.19	3.0	3.2
Heating System type	Gas Furnace	Gas Boiler	Gas Boiler	Gas Furnace	Gas Furnace	Gas Furnace
Heating system Capacity (kBtu)	540	840	900	1500	810	400
Heating Efficiency (%)	80	80	80	80	80	80

* System Type Definition:
DDS Dual Duct System
VAV Variable Air Volume
MZS Multizone System
SZS Single Zone System
PSZ Package Single Zone

Table 2. Comparison of Simulated and Monitored Data

		Total Building Load			HVAC Load		
Level	Area (sq.ft.)	Simulated (kWh/sq.ft.)	Actual (kWh/sq.ft.)	% Diff.	Simulated (kWh/sq.ft.)	Monitored (kWh/sq.ft.)	% Diff.
Office #1							
As Collected	15930	50.752	55.19	-8.0%	15.195	15.79	-3.8%
Billing Reconciliation	15930	50.752	55.19	-8.0%	15.195	15.79	-3.8%
Equipment Inspection	15930	50.752	55.19	-8.0%	15.195	15.79	-3.8%
Whole Building Loadshape	15930	53.543	55.19	-3.0%	17.446	15.79	10.5%
Monitored Lighting	15930	55.142	55.19	-0.1%	17.156	15.79	8.7%
Office #2							
As Collected	45677	19.835	21.56	-8.0%	2.800	3.66	-23.5%
Billing Reconciliation	45677	20.684	21.56	-4.1%	2.956	3.66	-19.2%
Equipment Inspection	45677	20.806	21.56	-3.5%	3.793	3.66	3.6%
Whole Building Loadshape	45677	20.183	21.56	-6.4%	3.943	3.66	7.7%
Monitored Lighting	45677	20.146	21.56	-6.6%	3.939	3.66	7.6%
Office #3							
As Collected	35327	12.011	13.96	-14.0%	2.176	2.84	-23.4%
Billing Reconciliation	35327	13.072	13.96	-6.4%	2.286	2.84	-19.5%
Equipment Inspection	35327	13.198	13.96	-5.5%	2.318	2.84	-18.4%
Whole Building Loadshape	35327	14.431	13.96	3.4%	2.364	2.84	-16.7%
Monitored Lighting	35327	14.739	13.96	5.6%	2.380	2.84	-16.2%
Retail #1							
As Collected	26526	23.406	17.71	32.2%	7.400	5.81	27.4%
Billing Reconciliation	26526	19.269	17.71	8.8%	6.564	5.81	13.0%
Equipment Inspection	26526	19.205	17.71	8.4%	6.694	5.81	15.2%
Whole Building Loadshape	26526	20.244	17.71	14.3%	7.744	5.81	33.3%
Monitored Lighting	26526	18.301	17.71	3.3%	7.292	5.81	25.5%
Retail #2							
As Collected	61182	26.378	23.41	12.7%	4.742	4.78	-0.8%
Billing Reconciliation	61182	24.695	23.41	5.5%	4.719	4.78	-1.3%
Equipment Inspection	61182	24.950	23.41	6.6%	4.974	4.78	4.1%
Whole Building Loadshape	61182	25.006	23.41	6.8%	4.821	4.78	0.9%
Monitored Lighting	61182	23.072	23.41	-1.4%	4.443	4.78	-7.1%
Retail #3							
As Collected	23116	23.748	36.08	-34.2%	3.957	5.5	-28.1%
Billing Reconciliation	23116	32.587	36.08	-9.7%	5.481	5.5	-0.3%
Equipment Inspection	23116	33.105	36.08	-8.2%	5.617	5.5	2.1%
Whole Building Loadshape	23116	35.288	36.08	-2.2%	5.313	5.5	-3.4%
Monitored Lighting	23116	33.123	36.08	-8.2%	5.265	5.5	-4.3%

average summer weekday hourly loads by test building and level of data. The data used to calculate these errors re the average summer weekday load profiles which are presented graphically in Figures 2 through 7 for the six buildings studied. These statistics, along with Figures 2 to 7 provide insight into the accuracy with which each analytical level estimates the average demand profiles. Inspection of Tables 2 and 3 and Figures 2 to 7 demonstrates that in general each additional level of data improved the performance of both energy and demand profile estimation for this sample of buildings, although there were some exceptions. The results for each level are discussed in greater detail below.

Level 1. Simulation based solely on on-site data collection generated average absolute EUI estimation errors of 18.2 percent for total building consumption and 17.8 percent for HVAC consumption. The absolute estimation errors for whole building EUIs ranged from 8 to 36 percent for the six buildings studied. Absolute estimation errors for

Table 3. Load Estimation Comparison by Root Mean Squared Error

	Root Mean Squared Error of Average Hourly Summer HVAC Load (kW)					Percent Change in RMSE Relative to Previous Level			
Building Number	**As Collected**	**Billing Reconciliation**	**Equipment Inspection**	**Whole Building Load**	**Monitored Lighting**	**Billing Reconciliation**	**Equipment Inspection**	**Whole Building Load**	**Monitored Lighting**
Office 1	12.3	12.3	12.3	9.9	10.4	0.0%	0.0%	-19.9	%5.1%
Office 2	9.0	8.8	8.5	8.5	8.5	-2.1%	-3.3%	-0.6%	0.5%
Office 3	11.5	11.5	6.2	9.0	8.7	0.1%	-46.2%	45.6%	-3.9%
Retail 1	23.6	21.0	17.1	9.9	7.8	-10.8%	-19.0%	-42.2%	-20.8%
Retail 2	23.6	24.0	24.9	6.4	3.8	1.7%	3.6%	-74.4%	-40.5%
Retail 3	11.2	7.1	7.1	4.2	4.3	-36.9%	0.1%	-40.3%	1.3%

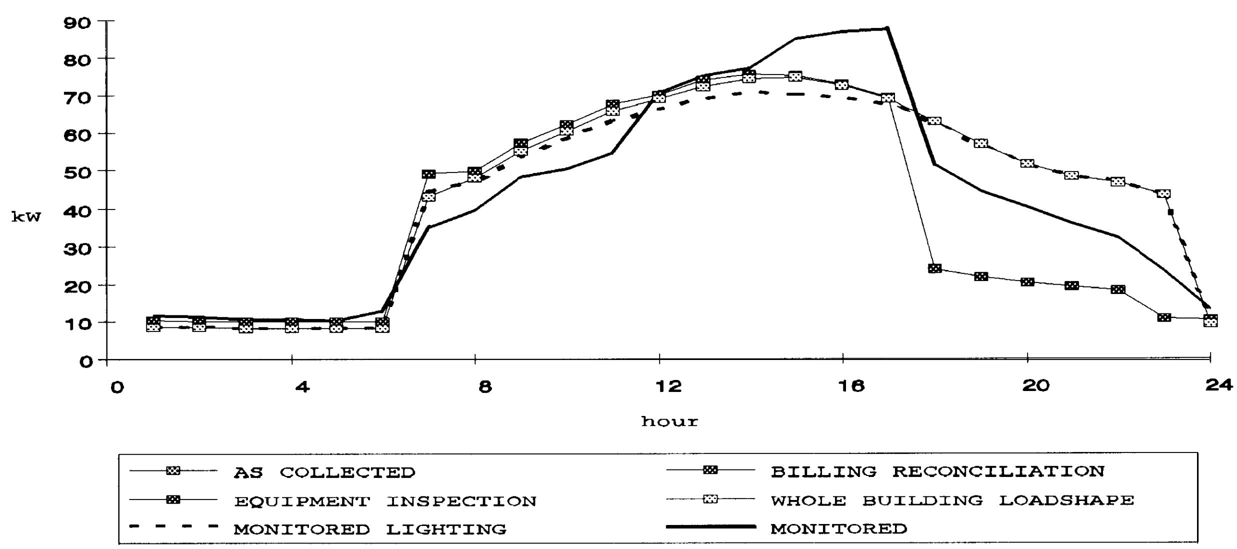

Figure 2. Average Summer Hourly Profile for Office #1

HVAC EUIs ranged from 1 to 27 percent. The root mean squared error for the average summer hourly HVAC load profile at this level averaged 15.2 kW. To put this number in perspective, the peak loads from the average summer hourly HVAC load profiles range from 40 to 100 kW for the six buildings studied.

Level 2. When the simulation input files were modified to account for billing data, the average absolute errors in EUI estimation improved to 7.1 percent for total building consumption and 9.5 percent for HVAC consumption. The whole building EUI errors improved for five of six buildings, and there was no change for the sixth. The HVAC EUI errors improved for four of the six buildings, with one building unchanged and one building with slightly higher error. The average root mean squared error for the summer HVAC load profiles was 14.1 kW. Significant improvements in load profile estimation were observed for the Retail 1 and Retail 3 buildings and modest improvements for the Office 2 building. There was no improvement in the Office 1 and Office 3 buildings and a slight increase in error for the Retail 2 building. Therefore, it can be seen that billing information offered substantial improvements for estimating energy consumption in this sample, but relatively modest improvements for estimating load profiles. The gain in accuracy observed from billing information was greater for whole building consumption estimates than for HVAC consumption.

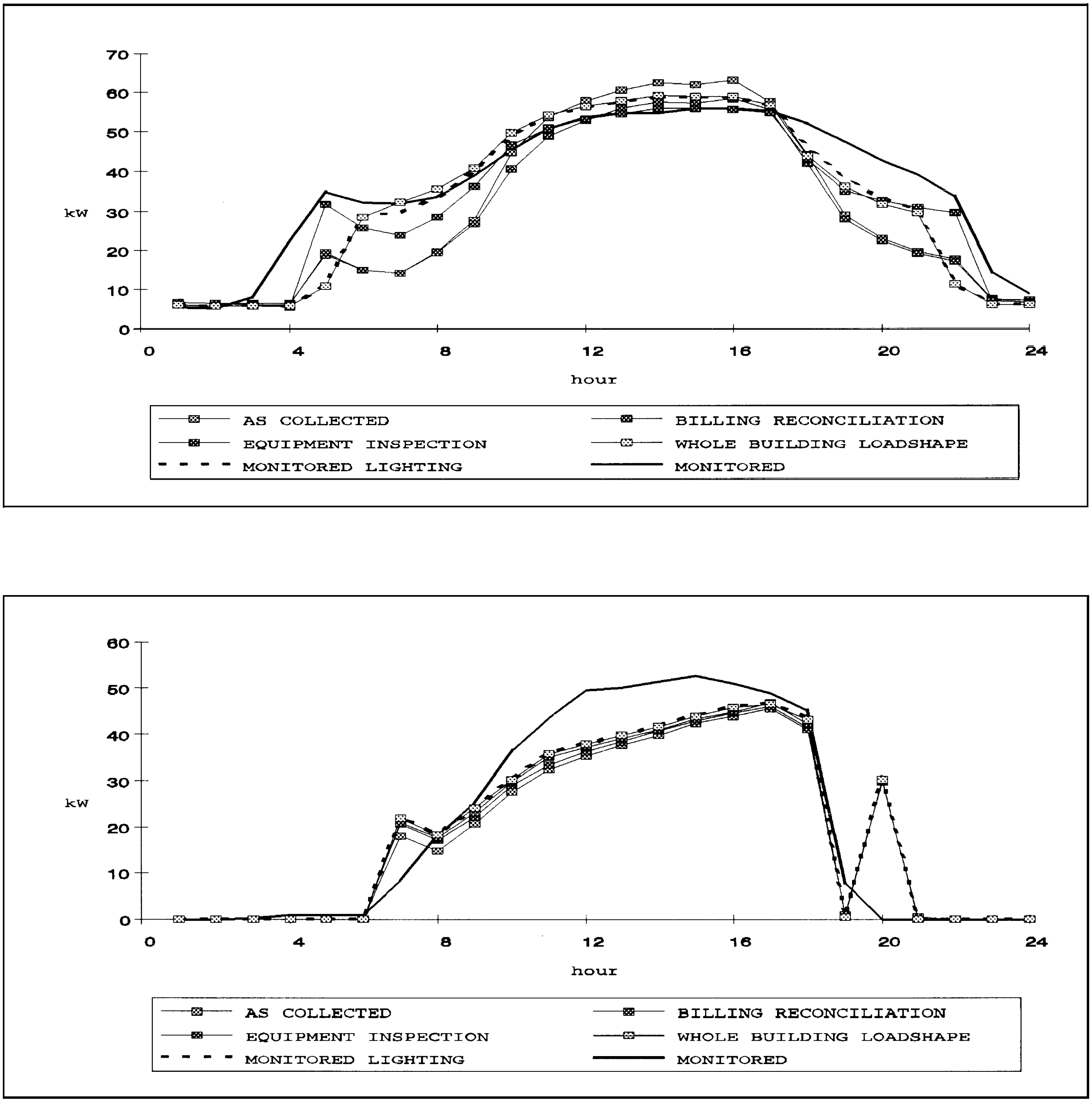

Figure 4. Average Summer Hourly Profile for Office#3

Level 3. When an HVAC inspection is added to the simulation input preparation, the average absolute EUI estimation errors fall to 6.7 percent for total building consumption and 7.9 percent for HVAC consumption. Four of the six buildings showed reduced error in whole building EUIs, one was unchanged and one had increased error. Just two of the six showed reduced error in HVAC EUIs, while three showed increased error. The average root mean squared error for the summer HVAC load profile was 12.7 kW. The load profile estimates for the 0ffice 3 and Retail l buildings improved significantly, and the Office 2 building improved modestly. The RMSE in the Office 1 and Retail 3 buildings was unchanged and there was an increase in RMSE for the Retail 2 building. The improvement in the HVAC consumption estimate was the most significant benefit observed from the HVAC audit, while the improvements in total building consumption and load profile estimates were more modest.

Level 4. With the addition of whole building load metered data to adjust simulation input, the average EUI estimation errors were 6.0 percent for total building consumption and

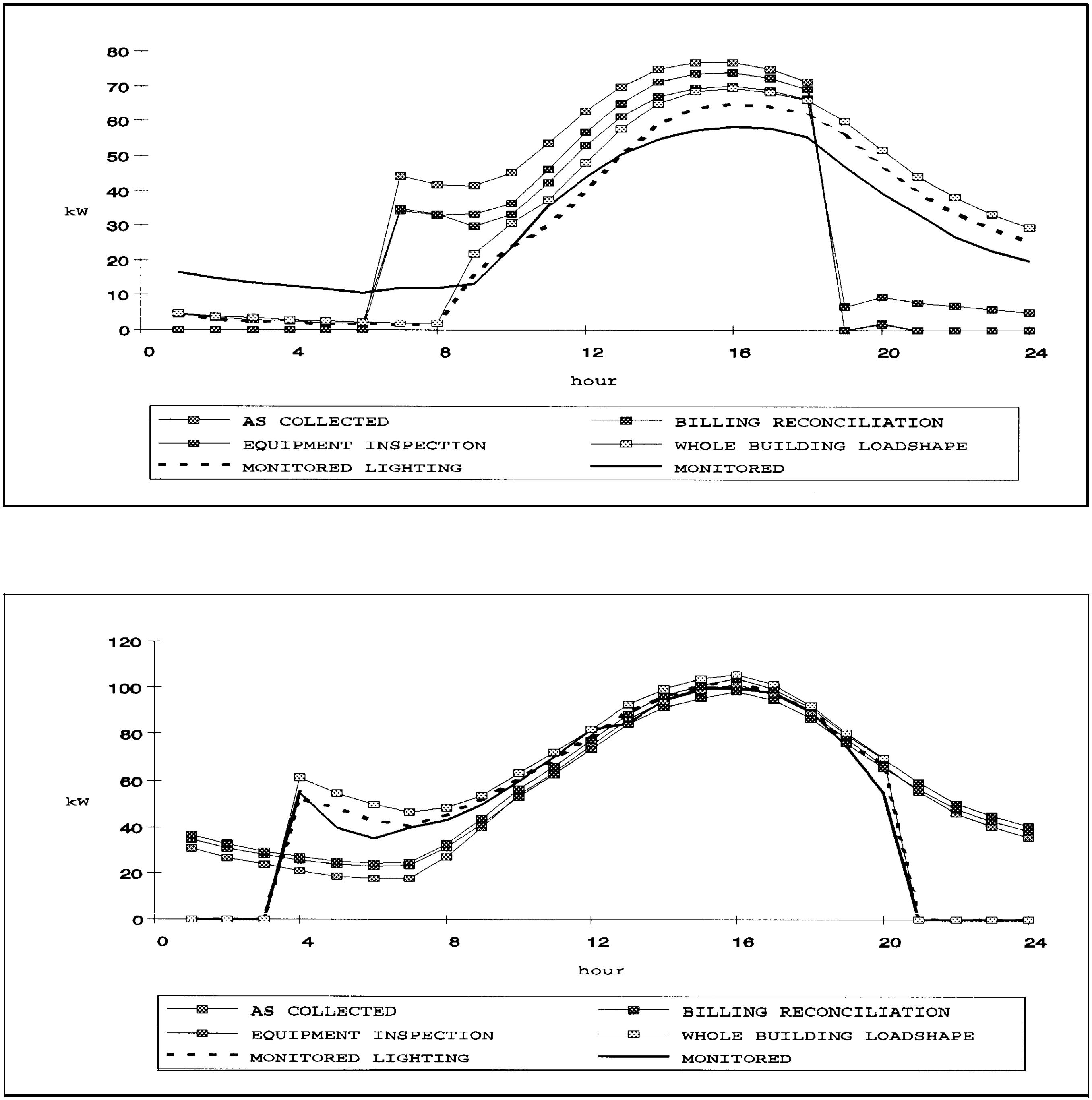

Figure 6. Average Summer Hourly Profile Retail #2

12.1 percent for HVAC consumption. Whole building EUIs improved for three buildings and worsened for three. The HVAC EUI errors were worse for five of the six buildings. The average root mean squared error for the summer HVAC load profile fell to 8.0 kW. The load profile estimates improved in five of the six buildings and a significant decline in accuracy was seen for one building. The load profile estimates in this sample improved dramatically with the whole building load data, but the gain in total building consumption estimation was more modest. The accuracy of the HVAC consumption estimate declined for this sample, although it is not clear whether that would be true for a larger sample.

Level 5. For the final level of analysis in which monitored lighting data was used to set simulation inputs, the average EUI estimation errors were 4.2 percent for total building consumption and 11.6 percent for HVAC consumption. The whole building EUI errors were better for three buildings and worse for three. For the HVAC EUIs, again three buildings had reduced absolute errors and three had

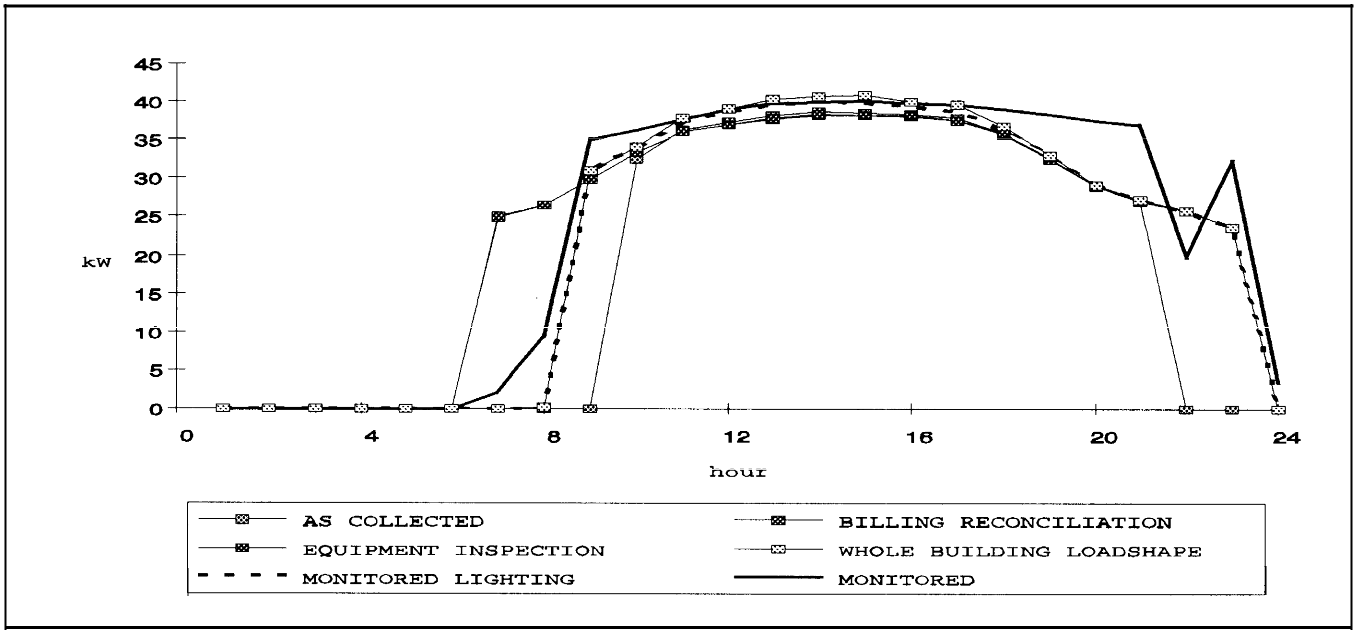

Figure 7. Average Summer Hourly Profile for Retail #3

increased absolute errors. The average root mean squared error for the summer HVAC load profile dropped to 7.3 kW. Significant improvements were seen in the load profiles estimates for the Retail 1 and Retail 2 buildings, and a modest improvement was seen in the Office 3 building. The remaining three buildings had small increases in RMSE from the previous level. The improvement in the total building consumption estimate was the most dramatic observed at this level, and the improvement in the load profile estimate was also significant. The improvement in the HVAC consumption estimate was fairly modest.

Conclusions

In progressing from Level 1 to Level 5 load estimation procedures, the average estimation error observed for whole building consumption was cut by 77 percent, with the greatest gains coming from billing data and lighting monitoring data. The average estimation error for HVAC consumption was cut by just 35 percent. The greatest gain in HVAC consumption estimation accuracy was with the addition of billing data, while the use of whole building load data was accompanied by a decline in HVAC consumption accuracy. The average root mean squared error for summer HVAC load estimation was cut by 52 percent. The most significant gain in load estimation was observed with the addition of whole building load data.

Overall, this study supported the conclusion that simulation with monthly billing reconciliation provides reasonable results for estimation of annual HVAC use. However, based on this study, whole-building load data are needed to achieve reasonable estimates of HVAC load shapes. This is supported by Figure 8, which represents the average load shapes for the six buildings studied for levels 2 and 4. The availability of monitoring data limited the number of buildings which could be examined in this study, so it would be useful to extend this analysis to a larger sample of buildings as data become available to confirm these findings.

Endnotes

1. "Commercial New Construction Evaluations" prepared for Southern California Edison Company by ADM Associates, Inc., 1993

2. "Development of Commercial Building Load Shapes" prepared for Pacific Gas and Electric Company by ADM Associates, Inc., 1993

3. Schon, Andrew and Rodgers, Robert, "An Affordable Approach to End-Use Load Shapes for Commercial Facilities," ACEEE Proceedings, September 1990.

4. "Impact Evaluation of Energy Management Hardware Rebate Program" prepared for Southern California Edison Company by ADM Associates, Inc., 1993

5. "End-Use Metered Data for Commercial Buildings" prepared for Southern California Edison Company by ADM Associates, Inc., 1991

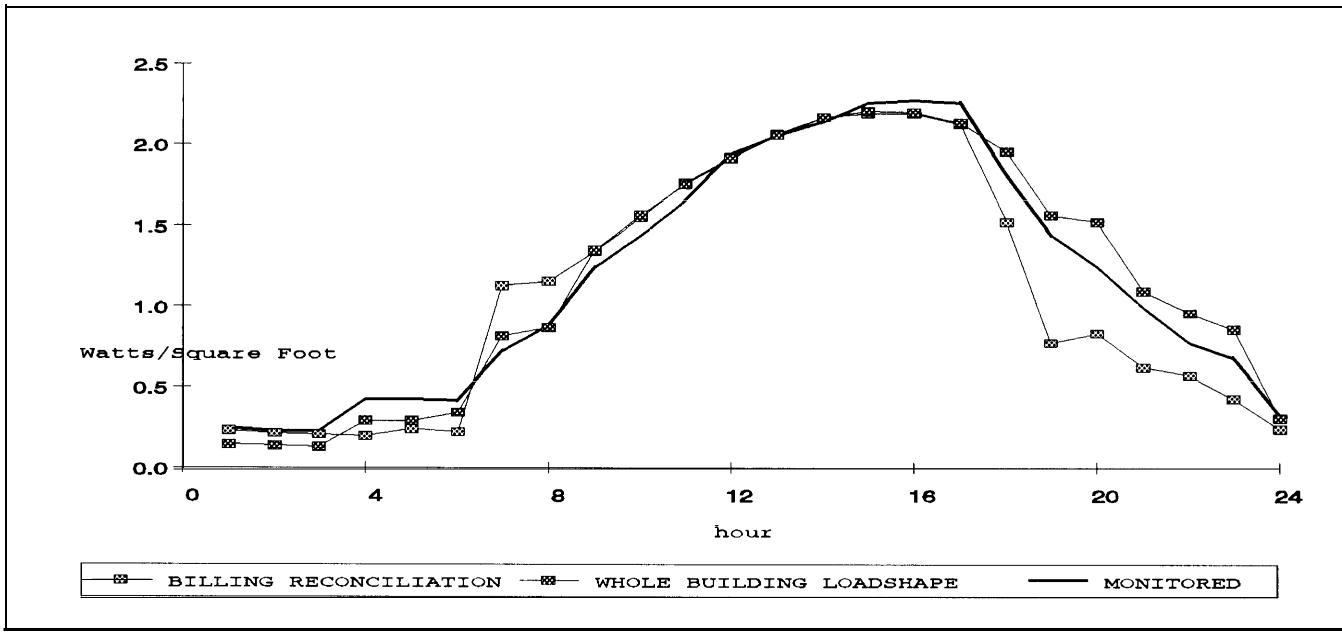

Figure 8. Average Summer Hourly Profile for All Buildings