A Comparison of Metered and Audit Results: Commercial Buildings

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The use of electricity by the commercial sector has been the focus of much research in recent years. Data has been gathered and analyzed using several methods and for a variety of reasons. Two of the large commercial sector data gathering projects at a midwest electric utility involved audits of conservation potential in a sample of 370 buildings and detailed end-use monitoring over a two year period in a subset of 60 of those buildings. The results from the buildings that were in both studies are compared in this paper. Topics covered include a comparison of energy use in several commercial building types at the end-use level and the accuracy of estimates of hours of operation of the buildings. Possible improvements to the audit process will also be discussed.

Introduction

In an attempt to help their commercial customers better understand how they use electricity and in turn use it more efficiently, Wisconsin Electric Power Company (WE) has been involved in two large data gathering projects, the Commercial Audit Program and the Commercial End-Use Metering Project.

Commercial Audit Program

Approximately 6,500 conservation audits have been conducted at commercial customer premises over the past seven years. The results of these audits have all been stored on a database used by company analysts to determine conservation potential and as inputs to forecasting and planning systems used in the integrated planning process. For the Commercial Audit Program a random sample of 376 customers were audited in 1987-88 as part of an effort to determine conservation potential in the commercial class and its sectors.

Commercial End-Use Metering Project

A project to meter the electric use at the end-use level in commercial buildings was begun in 1987. The major uses of electricity were identified and monitored for at least a two year period in sixty commercial buildings. The types of buildings and end-uses monitored are discussed in a later section of the paper. The project is further described in a later section of the paper.

Comparison of Results

There are many possible uses of two years worth of metered electric end-use data from a group of commercial buildings located in the upper midwestern part of the United States. The data can provide a detailed picture of the components of the hourly load profile of a building or a group of buildings over a wide variety of weather conditions. It might also be used to examine patterns peculiar to a specific end-use in a single building type, for example lighting in grocery stores. Another valuable use of the data would be to benchmark or suggest improvements to a statistical or engineering model developed for use in commercial buildings.

The possibility of comparing the CEUM results to audit results was first investigated in late 1989. Sufficient metered data was available at that time to allow such a comparison. As a first step, interior lighting values were compiled from each source and compared. A wide variation in results was found, with almost half of the sites differing by more than thirty percent. Based on these results, a decision was made to re-audit three of the buildings in an attempt to determine if the differences were caused by the data collection process or the software being used in the disaggregation. The results of this exercise, shown in Table 1, were mixed and work on this topic was put on hold for a period of time.

A more comprehensive comparison study was begun at the utility in 1991 to compare the metered data with the results from the auditing process. The focus was on an examination of the results of the two different methods of quantifying the components of electric use in the individual commercial buildings and also by building sectors. Three of the sixty monitored buildings were excluded in the study. One site, a large new office, was never audited.

Table 1. Repeated Audits Compared to Metered Results

	Audit #1 MWH/year	PCT #1 %	Audit #2 MWH/year	PCT #2 %	Metered MWH/year	PCT %
Restaurant:						
Total HVAC	13.0	3.6	29.1	8.6	61.4	17.7
Interior Lighting	61.4	16.9	42.7	12.5	29.7	8.5
Exterior Lighting	10.0	2.7	9.7	2.9	13.5	3.9
Miscellaneous	2.1	0.6	40.3	11.8	36.6	10.5
Refrigeration	26.8	7.4	44.1	13.0	54.1	15.6
Hot Water	111.1	30.5	34.9	10.3	33.8	9.7
Food Prep	139.8	38.4	139.5	41.0	118.3	34.1
Total Service	364.2	100.0	340.3	100.0	347.4	100.0
Grocery:						
Total HVAC	674.5	22.7	474.5	18.2	150.4	5.7
Interior Lighting	885.3	29.8	994.0	38.2	747.3	28.3
Exterior Lighting	26.6	0.9	47.9	1.8	25.8	1.0
Miscellaneous	111.4	3.7	96.7	3.7	217.2	8.2
Refrigeration	1,219.0	41.0	958.4	36.8	1,396.2	52.9
Hot Water	13.4	0.5	11.9	0.5	43.6	1.7
Food Prep	44.6	1.5	18.3	0.7	56.9	2.2
Total Service	2,974.8	100.0	2,601.6	100.0	2,637.4	100.0
Retail:						
Total HVAC	1,266.8	47.5	1,778.9	66.5	1,308.5	50.6
Interior Lighting	1,031.1	38.7	613.0	22.9	773.5	29.9
Exterior Lighting	32.9	1.2	74.6	2.8	68.6	2.7
Miscellaneous	234.8	8.8	194.9	7.3	336.6	13.0
Hot Water	70.0	2.6	14.1	0.5	0.0	0.0
Food Prep	29.3	1.1	0.0	0.0	99.2	3.8
Total Service	2,664.9	100.0	2,675.6	100.0	2,586.4	100.0

Another building changed from a shoe store to a used car dealer's office and was not re-audited. The last, a small restaurant, went out of business shortly after monitoring began.

Sampling Approaches

These projects were designed as part of an overall plan for data collection and storage by the utility to allow for the combination of data from various sources to obtain the best estimates possible for the least cost. The intent was to leverage a limited amount of more expensive end-use metered data with the audit results and whole building load research data. This study is one example of this leveraging process. Another project in progress is a tailored collaboration effort with EPRI to develop end-use load shapes for commercial class buildings.

The samples for both the audit program and the end-use metering project were designed using the Model-Based Stratified Sampling (MBSS) methodology designed for use in electric utility load research. Both samples were stratified by building type and energy use. Audits were done in each of the building types. Because of the expense involved with doing end-use metering, the decision was made to concentrate on the building groups with the greatest energy usage since they would provide the greatest potential for conservation.

After careful consideration, it was decided that the end-use sample would be embedded in the audit sample. The major advantages were having both sets of data on the same building and having access to the audit information for use in recruiting the end-use metering participants. A major disadvantage was the availability of the audit results to all the monitoring participants early in the data collection period. The concern was that the customers would make changes to their facility based on the information they received from the audits. Seventeen of the building owners did implement some type of conservation measure during the monitoring period, mostly in response to a very comprehensive demand-side management program being conducted by the utility.

End-use Metering Process

During the design stage of the CEUM project, there were only three other large scale end-use metering projects in progress in the United States. There was a considerable amount of discussion with the people associated with these projects to ascertain the procedures to follow, equipment to use, things to do and even more importantly, the things NOT to do.

The office, retail, restaurant and grocery store sectors were selected as the primary participants in the project based on energy use. Five warehouses and three health buildings were later included because of the interest expressed by these building owners. Although procedures were established to insure that all the necessary tasks were done, each building monitored had its unique characteristics and a separate plan was developed for the site.

The guideline used for determining the end-uses to be monitored was whether the end-use contributed five percent or more to the electric load of the building. Lighting and HVAC were monitored in all the buildings, but the remaining uses varied from one building type to the next. The number of channels of data collected from different buildings ranged from 4 to 36 with 12 to 16 channels being a typical mid-size installation. Recorder channels were available in multiples of four, so the decision on including minor end-uses at a site were often dependent on the availability of a channel. An end-use such as lighting that is dispersed throughout a building would often require several channels to capture the entire end-use.

The data were collected from the recorders, processed, validated and stored in a mainframe load research database management system. The capture rate for the 15-minute demands was greater than 95 percent for the 1350 channels of data. Quick access to the data is provided by the micro-computer based Data Analysis and Reporting System (DARS) which was specifically developed for use with the large amount of data being gathered as part of the project.

Audit Process

The audit package used on the buildings in the sample uses a hybrid approach to establish the facility end-use breakdown. This approach combines engineering calculations based on auditor inventoried data with a bill reconciliation process that reconciles (or limits) consumption to the actual fuel bill total. This approach dampens "user-effects" inherent in the data gathering process, lessening the impact that user assumptions and interpretations will have, thereby raising the level of accuracy of the results.

The audit process begins with a site visit during which a trained energy auditor gathers detailed information about the facility's operation. For up to seven standard end-uses, data that will be used to establish the starting point estimates for the bill reconciliation are collected. For example, for the lighting end-use all luminaries are inventoried and assigned to an auditor established use group. Within a facility, up to forty different lighting use groups, each with different hours of use, can be defined. Similarly, when applicable for the facility in question, inventory data describing heating and cooling profiles, domestic hot water consumption, cooking, and refrigeration, all with their associated equipment, are gathered.

This information is then entered into the computer. During this process quality control documents are produced which check for consistency and completeness of data (e.g., if natural gas is used for the space heating end use, is the heating equipment listed as gas fired). Once data are entered, the first step is to establish the end use breakdown. In further steps, auditor-identified opportunities for energy efficiency improvements are analyzed. Corresponding cost, savings, utility rebate, and payback with and without rebates are calculated for each measure. Based on an auditor identified payback threshold these measures are either recommended or vetoed. Quality control documents are produced in these phases and allow verification of all calculation results. Corrective intervention, such as changing hours of use or zone temperatures, can occur at any step. In the final step a report is prepared and delivered to the customer. The entire set of customer data is retained in a database that can be accessed for further analysis of equipment saturations, measure specific conservation potential and other customer characteristics.

Audit Software

The focus of this paper is on the end-use results obtained from the audit software as compared to those of the submetering project. To fully understand the comparison, an explanation of the software approach to the end-use breakdown is warranted.

Engineering Estimates

As stated earlier, the starting point in the software are the engineering estimates for all inventoried end-uses. This is when the data gathered during the site visit are used in their original form to calculate consumption. No judgments are made on the data at this point. They are assumed to be an accurate reflection of actual usage. These engineering estimates are used as input to the bill reconciliation process.

The estimate calculations fall into two categories; explicit and modeled. Explicit estimates result from direct calculation with information collected explicitly and entirely on-site. Lighting is an example of an explicit end-use. During the data collection process, wattages, fixture counts and hours of use are all gathered with an assumed high degree of reliability. The calculation of connected kW and annual kWh come directly from the auditor inventory. Another example where explicit estimates define the end use include up to a possible twenty auditor defined non-standard end uses.

Modeled estimates typically include engineering assumptions. While any assumptions used are based on accepted practices, all are readily editable and could be modified if their accuracy were in question. Heating and cooling are examples where modeled estimates are used to define the end-use. Inventoried temperature profiles, qualitative estimates of space gains and exposure, and associated equipment data are fed into a bin method calculation. While occupied and unoccupied times and corresponding temperatures are obtained explicitly, estimates on a scale of 1 to 10 of gains and exposure are entered by the auditor and are quantified by the audit package software using derived values. Further, quantitative judgements of efficiencies are made by the software based on inventoried equipment type, size and age. The bin method calculation yields the starting point estimate for the heating and cooling end-uses. Refrigeration, cooking, and process are other examples where modeled estimates are used to define the end-use. Modeled end-uses would be the primary target of any starting point modifications.

Fuel Bill Reconciliation

The next step in the end-use breakdown process is reconciliation to actual annual fuel bills. The software applies a constraint that says the total of all end-uses can not exceed the actual fuel bills. With actual fuel bills being the ultimate arbiter for the building end-uses, care must be taken to properly define "the facility" and its associated billing. For the process to yield accurate results, the twelve months of fuel bills provided with each audit must represent the inventoried data. Further, the inventoried data should represent actual usage as close as possible. Buildings with multiple meters, meters with multiple buildings, and buildings where site escorts are unfamiliar with the building require proper diligence.

In the reconciliation of allocation process, end-use assignments and reported fuels are assumed to be correct. Inventoried end-uses are given their calculated starting point estimates. End-uses that did not have inventory data are assigned starting point based on database derived values for the facility type and size. Statistical confidence levels are assigned to each of the starting point values. End-uses with inventory data are assigned higher confidence levels than end-uses based only on database values. Explicit estimates are given the highest confidence levels, and as such have the highest priority for allocation.

To achieve the reconciliation, a constrained non-linear optimization model is used to operate simultaneously on all fuels and all end-uses to produce the most likely estimate of each end-use, given the available data. "Flags" have been installed to indicate when the reconciliation process forces any end-use beyond a threshold confidence level. In these cases, there is most likely a data error in either the reported fuel usage or in the inventoried data.

Objectives and Issues

A primary reason for doing both of these large projects was to help make better estimates of conservation potential in commercial buildings for demand-side planning purposes. There is an obvious trade-off involving cost and accuracy between the two methods. Monitoring is more expensive, but when properly carried out, yields a more accurate breakdown of electric use in a building. Conducting a comprehensive audit in the same building is less expensive, but will generally produce a less accurate breakdown of energy use. Given this trade-off and the availability of the two bodies of data, the next logical step was the comparison of the findings of the two systems. This exercise was useful in determining the accuracy of the audits, and to improve the audit analysis software if necessary. The audits will continue to be the primary tool used in the determination of conservation, while end-use metering will be used in special instances such as a new or improved technology testing.

Several areas of possible study became evident or were reinforced while comparing the results of the audit and monitoring projects, both from comparing individual buildings and comparing end-uses within and across building types. These included:

1. The importance of securing the correct billing data for use with the audits.

2. The possibility for improvement to the algorithms being used to disaggregate total building use to end-uses. Several trends were noted for specific end-uses within sectors or across all buildings. (See Figure 1.)

3. The identification of points in the audit process for further quality control checks.

4. Allowing for a modification to incorporate the effect of non-normal weather over the previous year.

5. Breaking HVAC into its components.

6. Estimates based on seasonal or monthly periods rather than annual.

7. A better method of determining hours of operation of a business.

8. Improve the auditor training so they are aware of the consequences of improper data collection.

Changes are already in progress to adapt the audit process to better represent the customers served by WE. They include service territory weather normalization, lighting definition enhancement and the separation of air conditioning into its ventilation and cooling components. These changes and any others that may follow may be validated and fine-tuned by running the monitored sites through the process as often as needed.

Comparisons

When comparing the results of the audit process and the end-use metering project several cautions are necessary. The audits were conducted for a different period of time than that covered by the sub-metering project. The initial comparison of the results was made using different time periods. Although such a comparison can highlight inaccuracies introduced in the data gathering step (so called "user-effects"), it is less useful as a basis for modification of algorithms. With possible modifications to engineering assumptions being one goal of the comparison, the next step entailed re-running all the audits using the actual sub-metered totals.

Subsequent runs with updated billing histories that matched the sub-metering totals showed that results aggregated by facility type were markedly improved. Figure 2 shows a comparison of all the buildings in the study after the change. This step eliminated error caused by the inaccurate billing histories obtained by the auditors. It also underscores the need to ensure that the correct billing data is selected for the facility being audited.

One of the most useful steps in determining the accuracy of the estimated data and the final allocation value has been the comparisons of sub-metered data, the estimates from the auditor inventory, and the final allocated values for individual buildings. The graphs in Figures 3a, 3b and 3c illustrate the fact that user effects and quality of data collection must be a part of the analysis to provide more accurate algorithm calibrations.

Facility 17 - is an example of a facility definition problem. The total consumption provided for the initial audit again does not even come close to matching the metered amount. The allocation values were computed twice, once using the original billing data and the second time more successfully using the metered total.

Facility 62 - shows an example of the allocation process reducing overstated HVAC consumption.

Facility 11 - shows the use of the allocator when the auditor inventory overstates consumption. The lighting estimate corresponds closely with the metered data, but the refrigeration estimate is too high. The allocated value for refrigeration provides a much better match with the metered result.

Facility 24 - corresponds closely on all end uses and indicates an excellent auditor inventory.

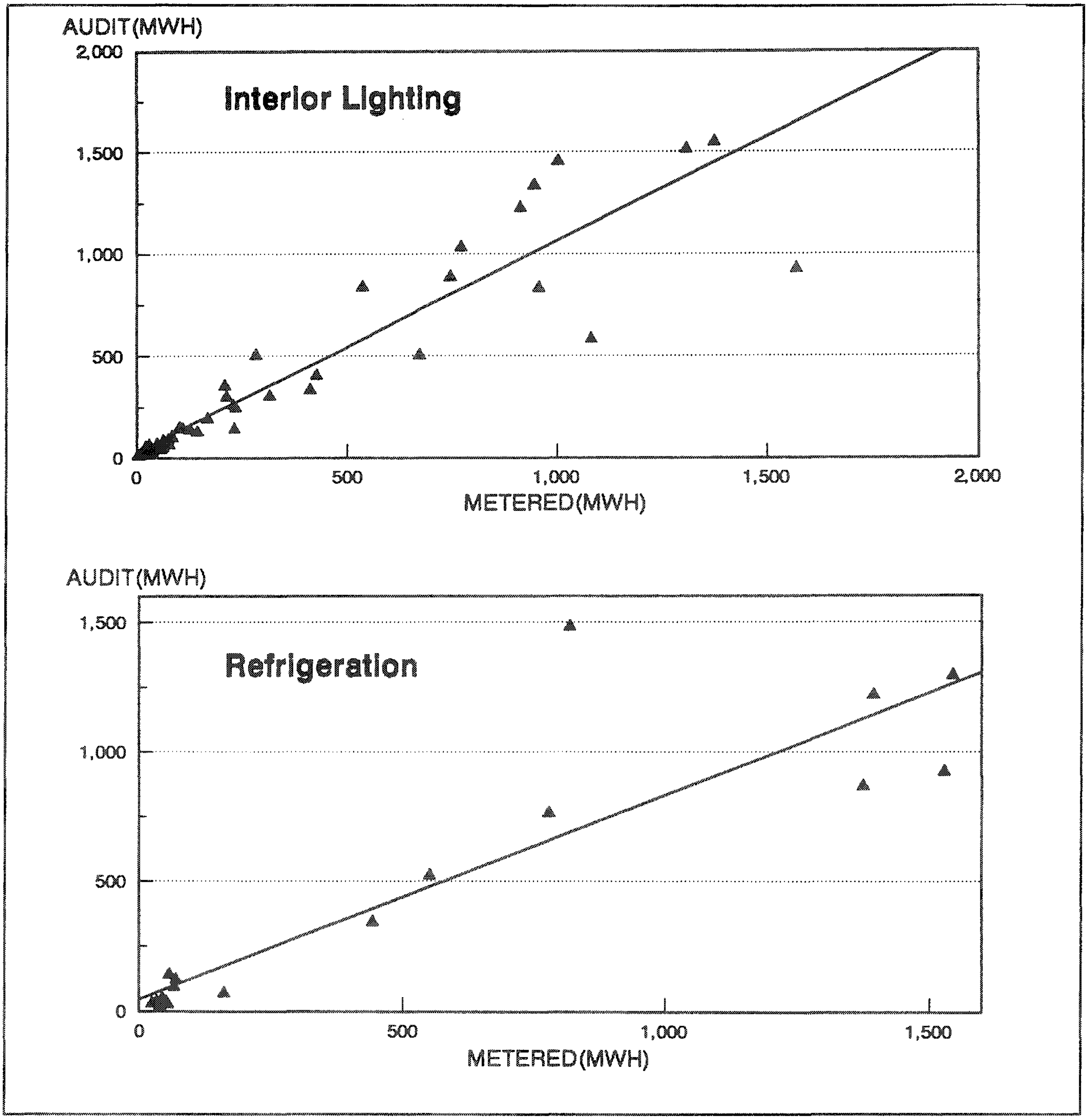

Figure 1. Least Squares Fit - Metered vs Annual Energy Use

Facility 101 - illustrates the effect that overstated lighting can have on other end uses, in this case refrigeration. The lighting discrepancy was accounted for in the refrigeration use because larger deviations are allowed for refrigeration.

Facility 4 - shows the effect of improper auditor inventory in the building. The audit inventory only accounts for half of the electric consumption.

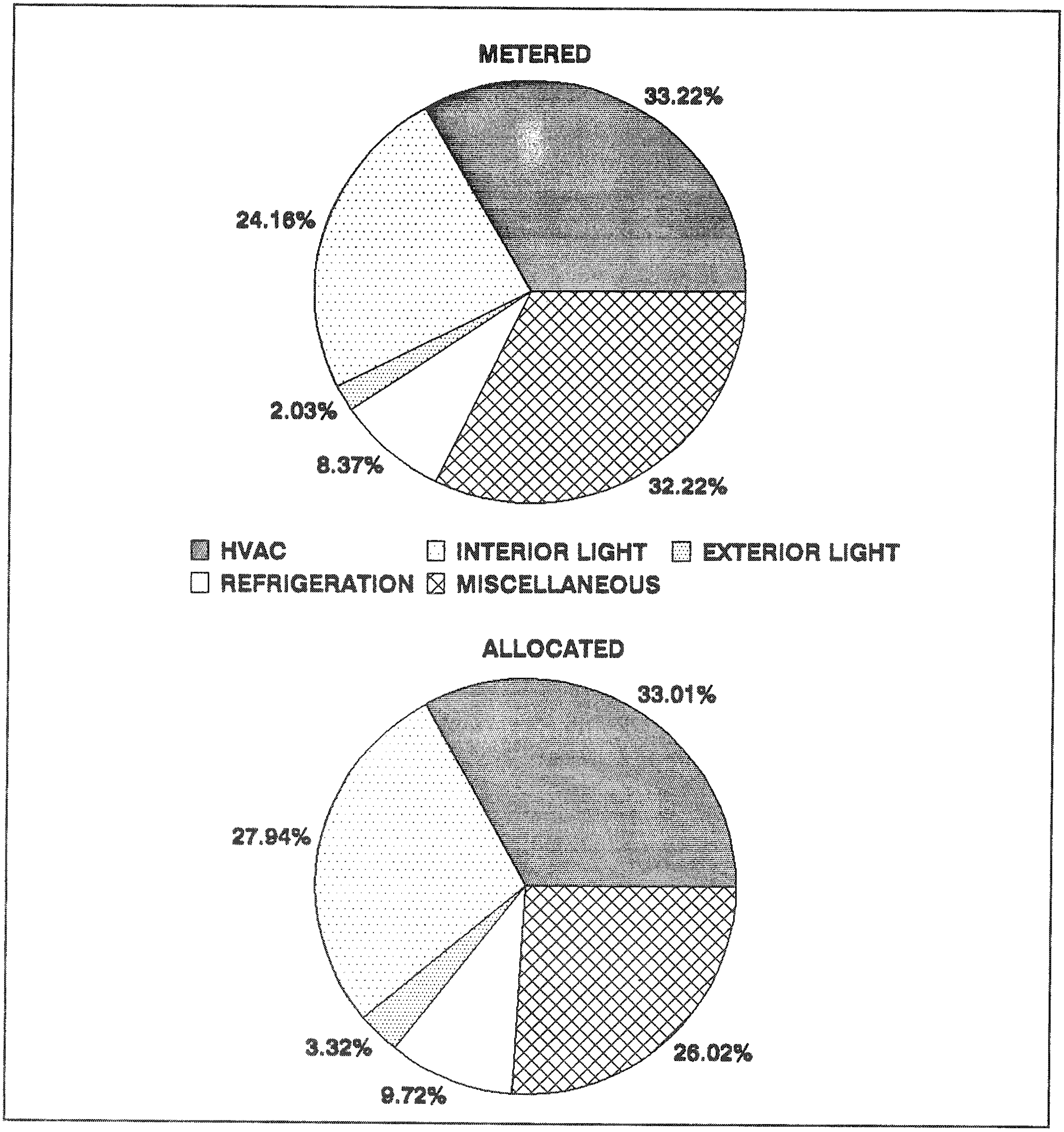

Figure 2. Comparison of End Uses in All Buildings Metered vs Audit

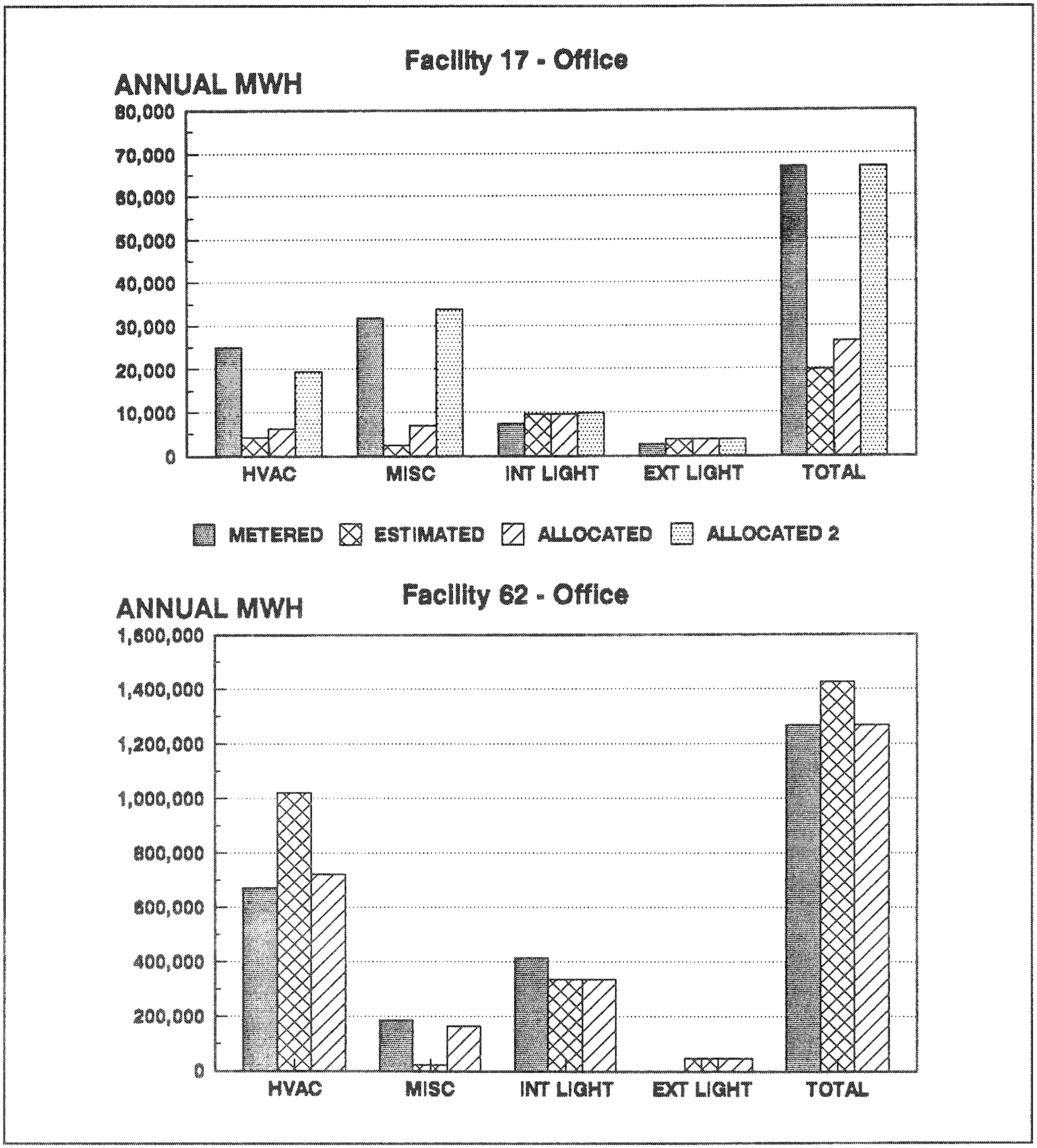

Figure 3a. Individual Building Comparisons

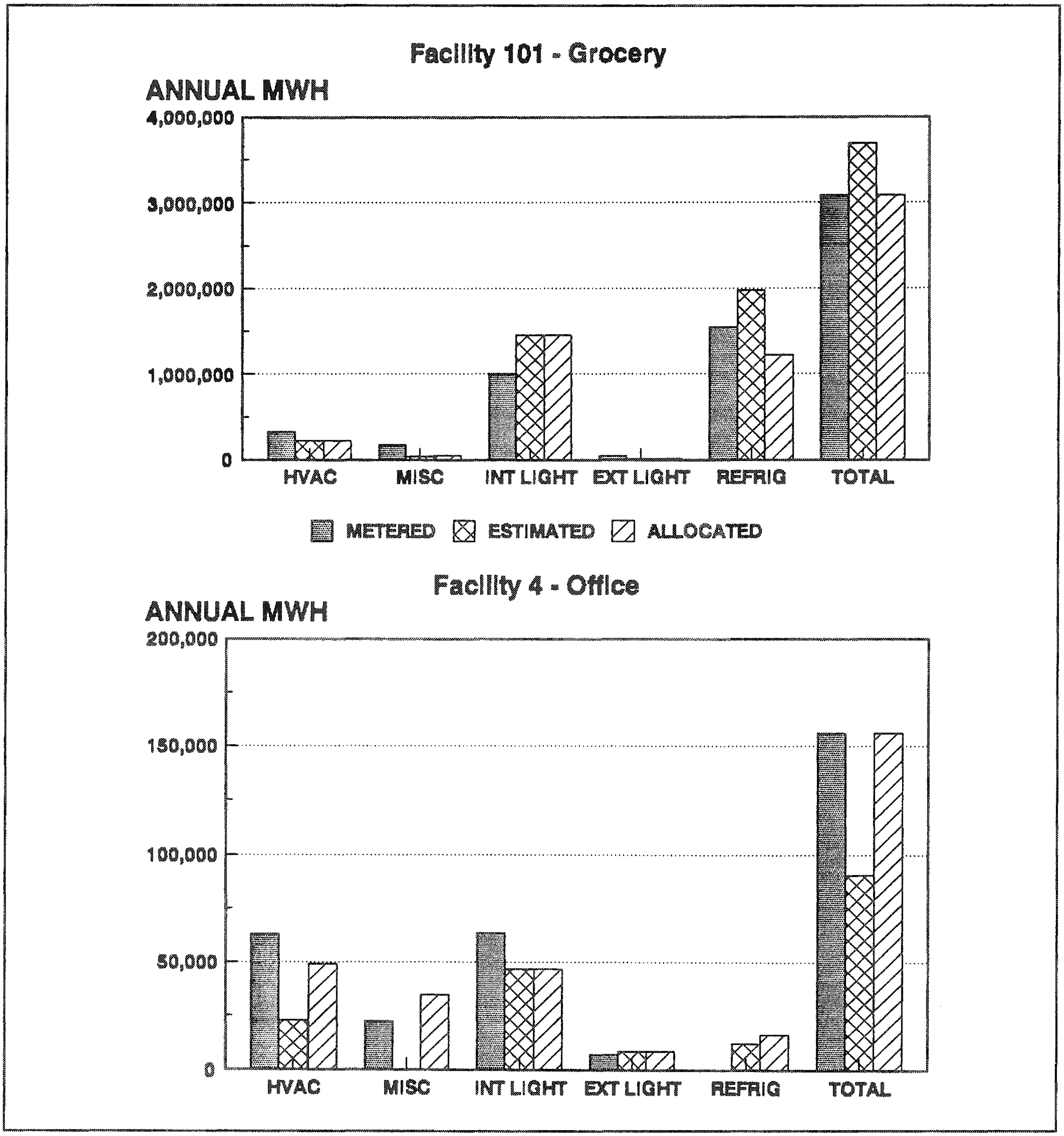

Figure 3b. Individual Building Comparisons

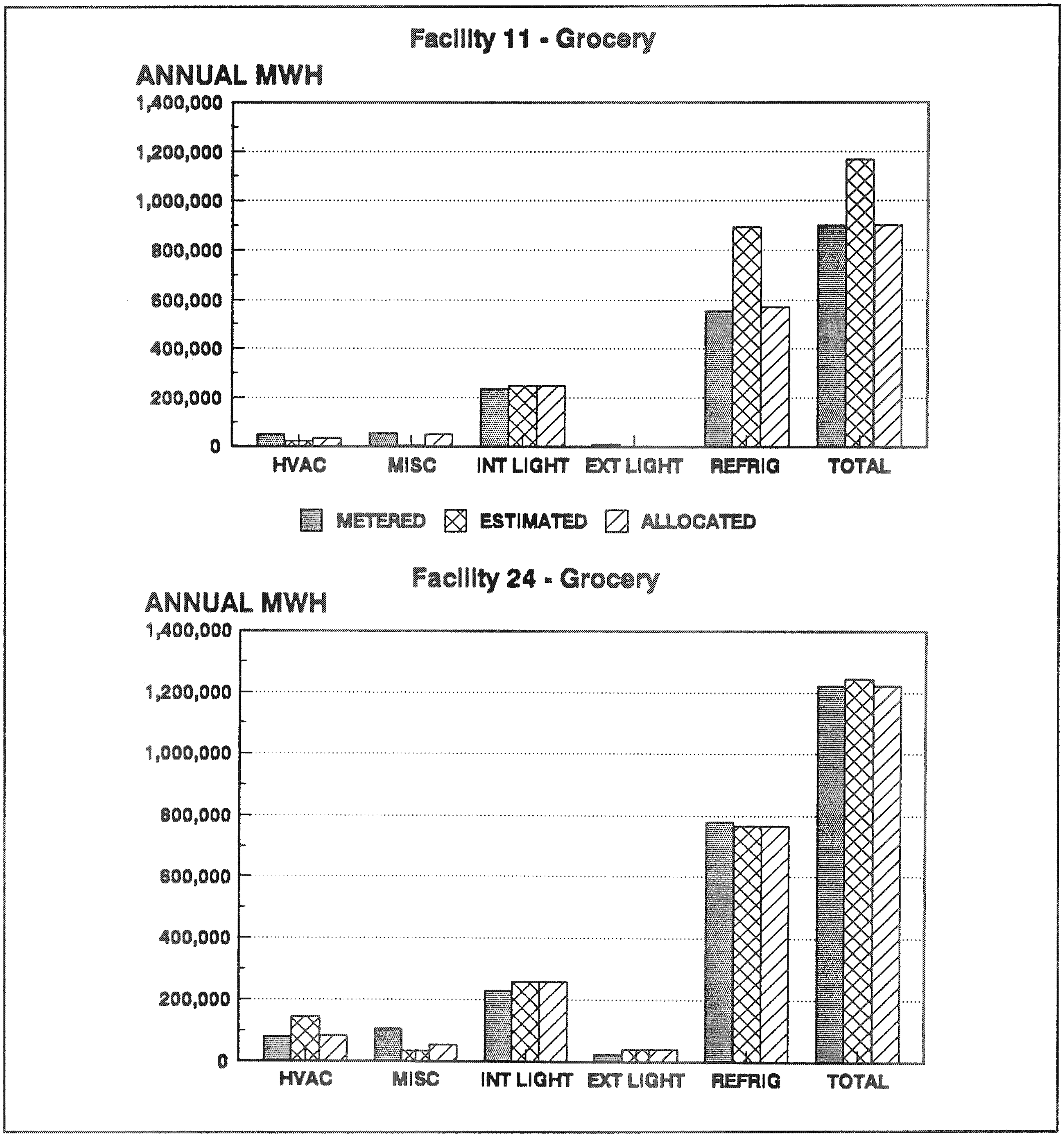

Figure 3c. Individual Building Comparisons

In the allocation process the lighting end-use is given the highest confidence level and as such is rarely changed from the starting point value obtained from the inventory data. As a result, deviations in the lighting end-use are absorbed by other electric end-uses. The comparison suggests that this high level of confidence should be revisited. However, when lighting corresponds closely with the sub-metered value and other starting point estimates vary significantly from the sub-metered values, the allocator tends to move the final end-uses closer to the sub-metered value.

Direct comparison of heating, cooling and ventilation end-uses were complicated by the fact that the audit and metering projects did not group all three in the same manner. While heating and cooling could be summed and ventilation could be assigned a portion of the "miscellaneous" category, errors in one could cancel errors in another. For a thorough comparison of HVAC results, resolution to the individual end-use level would be necessary.

Refinements

As an outcome of the comparisons, possible refinements to the end-use breakdown process have been investigated. Refinements in two key areas have been discussed. The first is to lower the confidence level, raising the standard deviation, on the implicit lighting estimates. The second involves review of the assumptions embedded in the modeled estimates. At this point these require more detailed study, including review of specific data on individual end-uses.

One area of refinement that does not involve software modifications, but will have an impact is the area of auditor training. It is clear from the data that errors in the data gathered can have profound effects on the outcome. Auditors must be trained to be diligent in all aspects of their work, and should be educated as to the potential uses of the data. In addition, the auditors should carefully review the quality control reports that are generated that indicate problems in the estimated data.

Conclusions

The CEUM project was conducted with several uses of the end-use metered results in mind. This paper describes the application of the data to a modeling system based on engineering estimates that are part of a conservation audit package used to provide data which is, and will continue to be, extensively used for DSM planning purposes by the utility. Further insight has been gained as to the factors driving the audit procedure and steps are being taken to improve the process.

This study has indicated that "user effects" are more pronounced than had been previously expected. A need for an automated rejection process is required in the audit system to catch obviously erroneous results. A centralized quality control effort would also help improve the process. Having the person doing the audit return to the facility and explain the results to the building operator should also improve the results.

As indicated earlier, changes are being made to the audit process based on the end-use metered data. Many other projects are in progress and others will be undertaken using the massive amount of data collected through the CEUM and other end-use metering projects being done at the utility.

Reference

Diamond, S. C., C. C. Cappiello, and B. D. Hunn. 1985. User-Effect Validation Tests of the DOE-2 Building Energy Analysis Computer Program. ASHRAE Transactions 1985, Vol. 91, Pt. 2.