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MONITORING APPROACHES FOR ENERGY CONSERVATION IMPACT EVALUATION

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ABSTRACT

Evaluations of retrofit projects in populations of buildings have shown that only about two-thirds of the savings are being realized. Field monitoring is used to help explain the discrepancies and improve the engineering estimates of savings.

A discussion of building monitoring program design for verifying retrofit savings is presented. The importance of monitoring the retrofit effect rather than the end use is stressed.

Short-term end-use monitoring is applied to verify the engineering estimates of direct, nonseasonal kilowatt-hour savings of a lighting rebate program for commercial and industrial buildings. Savings estimates are determined via room-by-room lighting surveys and estimates of weekly operating schedules. Typical lighting circuits in each building are also metered for at least one week before and after the lighting retrofit, using instantaneous spot kilowatt metering before and after the retrofit to verify kilowatt demand savings by ballast and fixture type.

Results from the first 20 buildings indicated that only 72.8% of the utility-estimated savings were being realized. The detailed survey produced 86.9% of actual savings. The most important factors in improving engineering estimates of savings are an accurate determination of fluorescent ballast types in the pre-retrofit condition and the types of fluorescent fixtures that are present in the building.

INTRODUCTION

A large portion of the dollars currently being spent nationally on energy conservation is a result of demand-side management (DSM) programs sponsored by utilities. Expenditures are typically recovered through the rate base, and in some states utilities can recover lost profits and even receive incentives for rapid program implementation. As programs become operational, some of the focus is shifting toward program impact evaluation. A major component of impact evaluation is the accurate prediction of energy savings in individual buildings. Specifically, what are the time-differentiated energy savings of conservation measures, how well do these measures compare to predicted savings, and how persistent are the savings over time?

Evaluations that have been completed to date have shown that in populations of buildings, only about two-thirds of the projected energy savings are realized. For example, Diamond et al. (1990) report that preliminary results for energy edge buildings indicate a 20% savings rather than the 30% originally estimated. Furthermore, there can be wide variation between predicted and actual savings in individual buildings. Analyses of billing data and load research data have been used to estimate the energy savings in populations of buildings, but neither of these techniques provides insight into why savings fall short of engineering estimates. Measurements of savings at the main meter are distorted by other changes that occur in a building and provide no means of verifying the assumptions used in engineering estimates of savings.

The causes of variation in impact analysis can be explored using field monitoring to assist in desegregating the components that contribute to savings. One study (*Demand-Side* 1990) has proposed an impact analysis approach based upon a hybrid statistical engineering model with end-use technology monitoring applied to those measures for which impact is not adequately accounted for by other analytical techniques. Amalfi and Wright (1991) discuss the engineering calibration approach (ECA), which utilizes monitoring in conjunction with other techniques for impact evaluation. Given its expense, it is essential that field monitoring be efficiently applied to furthering understanding of energy conservation retrofits in buildings. The purpose of this paper is to discuss monitoring approaches to impact evaluation and to present one example of the application of monitoring in the evaluation of a conservation program.

DESIGN OF BUILDING MONITORING PROGRAMS

The design of building monitoring programs must reflect the objectives that are to be achieved. There are fundamental differences that must be addressed between an end-use load measurement, an impact evaluation, and a technological assessment. One might assume that an end-use load measurement will automatically capture conservation savings in commercial buildings. The rationale is that the end uses are recorded for a period of time, the measures are implemented, and the savings simply appear as reduced consumption by end use. While it is certainly true that the savings attributable to large-

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impact measures will be noticeable at the end-use level, there are other factors that confound the savings. Changes in building characteristics, use, and weather have significant effects on energy use. These effects create problems because implementation of measures in a building can occur over several months or even a couple of years. For example, HVAC options, such as a change in cooling plant, are typically implemented during the off season, requiring before/after comparisons of energy use to occur one year apart.

A technological evaluation is very different in that it focuses on the conservation device in extreme detail. In its purest form, this approach should produce a specification for the product and a detailed description of all features, functions, operating parameters, and performance potential. Technological evaluation can include both laboratory and building measurements. It should deal with typical applications, interaction with climate, product life, and maintenance requirements, as well as aesthetic impacts and customer perceptions. For example, consider the case of energy-efficient lamps and ballasts. The impact evaluation should address kilowatt reduction and kilowatt-hour savings and perhaps power factor. The variation in savings with fixture type as well as the effect on the HVAC system may also be considered. However, factors such as color rendition, flicker, harmonics, ballast performance and life vs. operating temperature, light diffusion by fixture type, and occupant perception of light quality are the province of the technological evaluation.

Technological evaluations produce data of value to engineers, utilities, and building owners. However, they are typically the province of research and development, and should not be addressed in an impact evaluation. There are many new technologies appearing on the market that should be evaluated. For example, Hughes and Hackner (1988) describe a detailed field evaluation of an advanced earth-coupled heat pump system. In the absence of such evaluations, estimates of technological performance vary. For example, Little (1989) and Chernick et al. (1989) evaluated the performance of direct-fired chiller heaters, with widely differing conclusions. Clearly, there is a national need for a technological evaluation of these systems that goes beyond what would be measured in an impact evaluation. However, the technological evaluation may not result in an assessment of the impact of retrofit measures in existing buildings. Rather, technological evaluations predict the potential performance of systems.

The goal of an impact evaluation is to isolate the retrofit effect; what would the energy consumption have been if the measure had not been implemented? Monitoring end uses in the hope that the retrofit effect will show up is to invite the influence of other factors. Rather, the goal should be to isolate the measures being implemented so that the impact of other factors can be reduced or eliminated. This approach not only provides a better impact evaluation than a traditional end-use load survey, it can also provide information on a significant number of technologies.

The activities involved in establishing field monitoring as described by Misuriello (1990) are shown in Table 1. The design of a monitoring program must begin with a plan of analysis that sets forth the goals of the evaluation. Typically, this involves verification of parameters used to calculate engineering estimates of savings. It includes data products, points to be monitored, information to be gathered in the audit of characteristics, desired accuracy, and sample design. The need to begin with defined objectives should be obvious, yet many impact evaluation programs have ignored this step, to their detriment. Once the plan of analysis has been established, a monitoring plan can be developed, designed to capture the data specified in the plan of analysis. Next a recruiting protocol is defined to obtain monitoring sites, which is particularly important in utility programs because utilities are concerned about minimizing inconvenience to their customers.

A field data acquisition system (FDAS) must be developed. This includes equipment selection, inventory, incoming inspection, site documentation, component assembly and testing procedures, and shipping. A data-handling system is required that consists of data retrieval, translation, verification, archiving, backup, and analysis. Finally, a project tracking system must be developed. This function is extremely important because a monitoring project consists of a large number of one-time tasks coupled with several ongoing tasks. Effective logistics are crucial to project success.

Once planning activities have been completed, the project can begin. Project implementation consists of the one-time tasks listed in Table 2 and the ongoing tasks listed in Table 3. Mobilization includes briefing all staff who will work on the project and will implement previously described project systems. Sites are selected according to the sampling plan and recruited. A site measurement plan is developed that consists of site-specific information needed to construct and install the monitoring equipment and documentation of the field data acquisition system itself. A pre-retrofit characteristics survey should also be conducted at this time.

The FDAS is specified, based upon site measurement information, and assembled and bench tested. The com-

TABLE 1
Activities Prior to Establishing a Building Monitoring Program for Impact Evaluation

- Analysis Plan
- Monitoring Plan
- Recruiting Protocol
- Field Data Acquisition Handling System
- Data Handling System
- Project Tracking System

TABLE 2
Project Implementation—One-Time Tasks

- Mobilization
- Premise Selection
- Recruiting
- Site Measurement Plan
- Pre-Retrofit Characteristics Survey
- Field Data Acquisition System (FDAS) Preparation Testing and Documentation
- FDAS Installation
- FDAS Start-Up
- Post-Retrofit Characteristics Survey
- Post-Retrofit FDAS Modification (if required)
- Data System Termination and Removal

pleted unit is shipped to the site with detailed installation drawings. Assembly, testing, and documentation of the FDAS in the laboratory greatly reduces both installation errors and the time that must be spent at the customer's premises. The FDAS is then installed. Data collection is verified from the sensor to the data base. Automatic verification checks are established as part of the data collection process such that data can be checked prior to archiving. After the retrofit has been completed, a post-retrofit characteristics survey is performed, and modifications are made to the FDAS and data base, if required, to monitor the post-retrofit building system. Finally, the FDAS is removed, and the site is restored.

Ongoing tasks, as shown in Table 3, include operation and maintenance of the FDAS and data processing systems. In many instances, data analysis and reporting are ongoing as well. It is advisable, for multiple-site projects, to split the data verification and analysis functions among multiple individuals to ensure that the project remains on schedule. Quality assurance and quality control are essential to successful monitoring projects. An active QA/QC program ensures that accuracy tolerances have been defined and that the project has been audited against those tolerances. Finally, given the variety of tasks and technical skills required for a monitoring project and the logistics involved in operating equipment at multiple sites, effective project management is essential.

This monitoring approach has been successfully applied in a number of programs. One very important application is commercial/industrial lighting retrofit programs, which are the largest commercial/industrial DSM programs in many electricity utilities nationwide. The following section describes a relatively straightforward impact evaluation of a commercial/industrial lighting rebate program.

TABLE 3
Project Implementation—Ongoing Tasks

- Data System Operation/Maintenance Tasks
- FDAS Operation/Maintenance
- Data Analysis
- Quality Assurance/Quality Control (QA/QC)
- Reporting
- Project Management

APPLICATION OF BUILDING MONITORING TECHNIQUES TO A COMMERCIAL/INDUSTRIAL LIGHTING REBATE PROGRAM

The purpose of this building monitoring project was to verify the direct, nonseasonal impacts of a lighting rebate program for existing commercial and industrial buildings and to improve the engineering estimation of savings developed from program rebate forms. This type of verification was accomplished using short-term metering with an instantaneous spot-metering approach. While long-term metering can provide the added benefits of seasonal variation, persistence, and interaction, it was determined that such a comprehensive approach would be used primarily in buildings where a combination of retrofit measures, including HVAC measures, were being implemented.

The short-term program was carried out as follows:

1. Each recruited site was surveyed before the retrofit. The existing lighting was surveyed, and an estimate of operating hours was made for every space that was to be retrofitted. These spaces are referred to as "affected space." The survey included instantaneous spot metering of typical fixture types to verify pre-retrofit kilowatt estimates, indications of which lamps were burned out, and footcandle readings. This survey provided verification of the pre-retrofit kilowatt demand and an estimate of operating hours by space.
2. To obtain a better estimate of the schedule, typical circuits were selected for monitoring. The areas served by these circuits shall be referred to as "monitored space." Since the purpose of the monitoring was to verify the operating schedule, care was taken to ensure that monitored circuits contained only lighting and that all lamps on the monitored circuits were operating. Monitoring equipment was installed at least a week prior to retrofit of the lighting. This approach was less costly than metering all the lighting, which must be done when HVAC interactions are to be investigated.
3. A week or more after the retrofit was completed, the affected spaces were resurveyed, and the monitoring equipment was removed.
4. Energy savings in the monitored space were determined two ways—based upon the pre- and post-retrofit surveys and the estimated operating schedule and based upon the instantaneous spot-metering and monitored data. Comparison of results between the two methods in the monitored space was used to

adjust calculations for the affected space where metering was not performed. The building type, summary of lighting retrofit measures, and the area affected by the lighting retrofit are shown in Table 4.

To date, results are available for 20 buildings. A total of 30 commercial and industrial buildings in a rebate program, plus 15 buildings in a commercial audit program, are scheduled to be surveyed and metered.

RESULTS

About 2,100 lighting retrofit measures were installed in the 20 buildings. A breakdown of the measures is shown in Table 4. Field surveys showed that 94.4% of the measures that appeared in the tracking system data base were actually installed in the buildings. Short-term metering of up to four data channels in each building resulted in metering of about 56% of the projected kilowatt-hour savings. A sample of metered data from a typical lighting circuit is shown in Figure 1. Note the extra consumption for the first full hour of operation each day. This is caused by fluorescent lamp warmup and typically is not apparent when the entire lighting end use is monitored because lighting circuits are turned on gradually.

For comparison purposes, data from the utility tracking system are compared to on-site data and metered data. Tracking system data are engineering estimates developed from the rebate forms. On-site data are based upon site surveys and estimates of operating hours by space. Metered data are obtained from spot watt readings and the monitoring system that was installed.

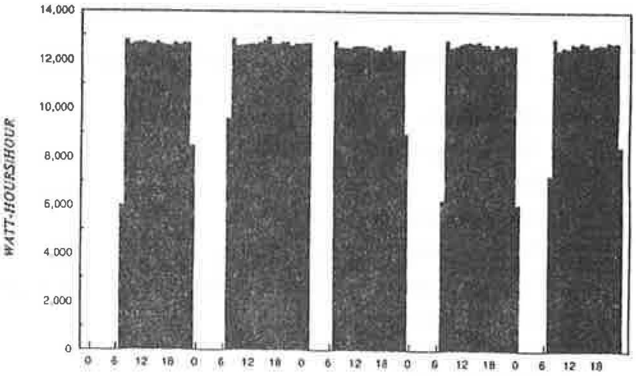

Figure 1 *Sample lighting hourly energy-use profile.*

Table 5 contains an hours-of-use comparison for the 20 buildings. The tracking system contained an average weekly lighting use of 66.10 hours per week, which was higher than the metered value of 57.75 hours per week. Three individual building hours-of-use ratios were developed. They are the ratio of metered operating hours divided by tracking system operating hours, metered operating hours divided by on-site survey operating hours, and on-site survey operating hours divided by tracking system operating hours. The ratios for metered vs. tracking system operating hours varied from 0.186 to 2.55. The space-by-space on-site survey resulted in an average of 56.45 hours of use per week. Individual building hours-of-use ratios varied from 0.275 to 1.660.

TABLE 4
Summary of Lighting Retrofit Measures by Building

ESLR SITE NUMBERS

SITE	SF	BLDG TYPE	MH/NA >200	MH/NA <=200	T8 SYS 3,4	T8 SYS 1,2	T8 SYS M 3,4	T8 SYS M 1,2	MOD CF	INT CF	LED EXIT	EXIT KIT	ELEC BAL T12,4,8	ELEC BAL T12HO	HYB BAL 4	INFRA ULTRA SENSOR	REFL 4,T12 U	REFL 8	REFL W/T8S REPL	TOTAL
702	1200	PUBLIC AREAS OF APTS							58											58
703	30700	OFFICE			11								52						532	595
704	3100	BAR/RESTUARANT/MEETING			25					6										31
706	2400	DAY CARE OFF CHURCH								45										45
707	300	OFFICE											12			2				14
708	23000	OFFICE			172	17							70	48						307
709	5500	OFFICE											88							88
712	10600	OFFICE/GYM			102	29														131
714	4600	OFFICE			75															75
716	14300	GROCERY/RETAIL			37				4				127							168
717	3500	OFFFICE			55															55
720	1092	MANUFACTURING/OFFICE			13	5							8							26
723	2700	BANK			14	14														28
724	1300	RESTUARANT			35															35
725	2600	OFFICE			45															45
726	2600	BANK			54															54
727	4100	BANK				121														121
728	44000	OFFICE				171														171
729	1900	RESTAURANT				35														35
730	2000	RESTAURANT			13	6														19
TOTALS	170692		0	0	651	308	0	0	62	51	0	0	357	48	0	2	0	0	532	2101

TABLE 5
Weekly Hours of Use

SITE NUMBER	TRACKING HOURS	ON-SITE HOURS	METERED HOURS	METERED HOURS/ TRACKING HOURS	METERED HOURS/ ON-SITE HOURS	ON-SITE HOURS/ TRACKING HOURS	ITRACKING HOURS -- METERED HOURSI	ION-SITE HOURS -- METERED HOURSI
702	50	83	64	1.280	0.771	1.660	14	19
703	75	58	68	0.907	1.172	0.773	7	10
704	70	70	13	0.186	0.186	1.000	57	57
706	40	25	22	0.550	0.880	0.625	18	3
707	60	84	55	0.917	0.655	1.400	5	29
708	60	57	48	0.800	0.842	0.950	12	9
709	40	44	38	0.950	0.864	1.100	2	6
712	65	50	55	0.846	1.100	0.769	10	5
714	50	45	48	0.960	1.067	0.900	2	3
716	110	115	118	1.073	1.026	1.045	8	3
717	50	34	31	0.620	0.912	0.680	19	3
720	50	50	50	1.000	1.000	1.000	0	0
723	55	50	52	0.945	1.040	0.909	3	2
724	65	55	48	0.738	0.873	0.846	17	7
725	50	25	21	0.420	0.840	0.500	29	4
726	20	15	51	2.550	3.400	0.750	31	36
727	80	22	50	0.625	2.273	0.275	30	28
728	80	25	55	0.688	2.200	0.313	25	30
729	126	113	134	1.063	1.186	0.897	8	21
730	126	109	134	1.063	1.229	0.865	8	25
AVERAGE	66.10	56.45	57.75	0.91	1.18	0.86	15	15

MEAN METERED HOURS / TRACKING HOURS = (57.75/66.10) = 0.874 HOURS
MEAN METERED HOURS / ON-SITE HOURS = (57.75/56.45) = 1.023 HOURS
MEAN ON-SITE HOURS / TRACKING HOURS = (56.45/66.10) = 0.854 HOURS

Both tracking system data and on-site data exhibited overestimation and underestimation of weekly hours of lighting use. These effects diminish somewhat when data from a group of buildings are averaged. The mean of the absolute value of the difference between estimated hours of operation and metered hours of operation for individual buildings is 18 hours for the tracking system and 13 hours for the on-site data, indicating that some form of metering is probably necessary for more precise determination of operating hours.

The change in kilowatt per measure is summarized in Table 6. This is where most of the variance in annual kilowatt-hour estimation occurs. The tracking system contains an average saving of 56.65 watts per measure, while the metered data showed savings of only 40.25 watts per measure. Spot watt readings of typical fixtures provided better results than the tracking system, agreeing with metered data to within 9%. However, the estimate of 43.90 watts per measure was still higher than the actual value. The problem is that many buildings contain a mixture of ballasts in the pre-retrofit condition. The assumption in the engineering estimate is that all pre-retrofit ballasts are standard electromagnetic ballasts. The on-site survey revealed that 14 of the 20 buildings contained significant numbers of high-efficiency electromagnetic ballasts, which have been available for about 10

TABLE 6
Change in Watts Per Measure

SITE NUMBER	TRACKING WATTS	ON-SITE WATTS	METERED WATTS	METERED WATTS/ TRACKING WATTS	METERED WATTS/ ON-SITE WATTS	ON-SITE WATTS/ TRACKING WATTS	ITRACKING WATTS -- METERED WATTSI	ION-SITE WATTS -- METERED WATTSI
702	48	17	14	0.292	0.824	0.354	34	3
703	19	66	44	2.316	0.667	3.474	25	22
704	106	62	62	0.585	1.000	0.585	44	0
706	54	80	82	1.519	1.025	1.481	28	2
707	60	17	16	0.267	0.941	0.283	44	1
708	76	68	63	0.829	0.926	0.895	13	5
709	24	14	13	0.542	0.929	0.583	11	1
712	76	51	49	0.645	0.961	0.671	27	2
714	80	67	59	0.738	0.881	0.838	21	8
716	39	26	23	0.590	0.885	0.667	16	3
717	80	59	59	0.738	1.000	0.738	21	0
720	54	48	49	0.907	1.021	0.889	5	1
723	60	35	40	0.667	1.143	0.583	20	5
724	80	61	55	0.688	0.902	0.763	25	6
725	80	44	37	0.463	0.841	0.550	43	7
726	32	21	18	0.563	0.857	0.656	14	3
727	66	33	20	0.303	0.606	0.500	46	13
728	32	30	24	0.750	0.800	0.938	8	6
729	22	24	20	0.909	0.833	1.091	2	4
730	45	55	58	1.289	1.055	1.222	13	3
AVERAGE	56.65	43.90	40.25	0.78	0.90	0.89	23	5

MEAN METERED WATTS / TRACKING WATTS = (40.25/56.65) = 0.711 WATTS
MEAN METERED WATTS / ON-SITE WATTS = (40.25/43.90) = 0.917 WATTS
MEAN ON-SITE WATTS / TRACKING WATTS = (43.90/56.65) = 0.775 WATTS

years. These ballasts are not as efficient as the electronic ballasts used in the rebate program, but they do reduce program savings. Spot kilowatt readings revealed the presence of high-efficiency electromagnetic ballasts. However, it was often difficult to precisely determine the percentage of these ballasts in a given building without more extensive spot kilowatt metering. The fixture type also affects the kilowatt savings, which are 6% to 8% greater in enclosed fixtures than in open fixtures. The ratio of metered kilowatt values to on-site spot watt readings varied from 0.606 to 1.142 as opposed to variations of 0.267 to 2.316 for tracking system data. Also, the absolute value of the difference between on-site and metered watts saved per measure was only 5 watts, as opposed to 21 watts for the tracking system estimates. Clearly, spot kilowatt readings can be used to improve engineering estimates of kilowatt savings, but the difficulty of estimating schedules remains.

The summary of kilowatt-hour savings is shown in Table 7. Note that in the mean, the on-site survey agreed with metered data within about 2%. The underestimate of hours of operation compensated for the overestimate of kilowatt savings in the on-site survey. On a building-by-building basis, the ratio of metered savings to on-site savings varied from 0.187 to 2.83, while for the tracking system data, the ratio varied from 0.100 to 2.025. Furthermore, the average of the absolute value difference between on-site and metered savings for individual buildings is 24% of average annual kilowatt-hour savings. The average of the absolute value difference between tracking system and metered savings is 72.7% of average annual kilowatt-hour savings. The on-site inspection and spot watt reading provided greatly improved consistency on a building-by-building basis.

CONCLUSIONS

A properly designed short-term monitoring program can be used to accurately determine the nonseasonal direct impact of lighting conservation measures in commercial and industrial buildings on a building-by-building basis if a proper set of monitoring and analysis protocols is followed.

Better building-specific agreement between engineering estimates and actual savings will require accurate determination of the pre-retrofit ballasts and fluorescent fixture type. These could be determined by the electrician who changes the ballasts.

Improvement in estimation of hours-of-use is best accomplished by metering. Short-term metering is the most cost-effective approach. Long-term metering is more costly but will provide information on persistence of seasonal variations and HVAC interaction.

Inclusion of fluorescent fixture type on rebate forms will also improve engineering estimates of savings.

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TABLE 7
kWh Savings

SITE NUMBER	TRACKING KWH SAVINGS	ON-SITE KWH SAVINGS	METERED KWH SAVINGS	METERED KWH/ TRACKING KWH SAVINGS	METERED KWH/ ON-SITE KWH SAVINGS	ON-SITE KWH TRACKING KWH SAVINGS	ITRACKING KWH -- METERED KWHI SAVINGS	ION-SITE KWH -- METERED KWHI SAVINGS
702	2842	4321	2607	0.917	0.603	1.520	235	1714
703	51761	117009	93937	1.815	0.803	2.261	42176	23072
704	13133	7047	1316	0.100	0.187	0.537	11817	5731
706	6852	4692	4233	0.618	0.902	0.685	2619	459
707	2602	1048	656	0.252	0.626	0.403	1946	392
708	70241	61914	48425	0.689	0.782	0.881	21816	13489
709	5741	2842	2235	0.389	0.786	0.495	3506	607
712	36450	17493	18557	0.509	1.061	.0.480	17893	1064
714	17680	11828	11095	0.628	0.938	0.669	6585	733
716	42391	25725	24068	0.568	0.936	0.607	18323	1657
717	11440	5660	5189	0.454	0.917	0.495	6251	471
720	4810	3276	3296	0.685	1.006	0.681	1514	20
723	4439	2569	3012	0.679	1.172	0.579	1427	443
724	9464	6048	4793	0.506	0.792	0.639	4671	1255
725	9776	2554	1838	0.188	0.720	0.261	7938	716
726	1265	905	2562	2.025	2.831	0.715	1297	1657
727	30618	4526	6236	0.204	1.378	0.148	24382	1710
728	23163	6876	11895	0.514	1.730	0.297	11268	5019
729	4796	4924	4806	1.002	0.976	1.027	10	118
730	5556	5936	7596	1.367	1.280	1.068	2040	1660
AVERAGE	17751	14860	12918	0.705	1.021	0.722	9386	3099

MEAN METERED KWH / TRACKING KWH = (12918/17751) = 0.728 KWH SAVINGS
MEAN METERED KWH / ON-SITE KWH = (12918/14860) = 0.869 KWH SAVINGS
MEAN ON-SITE KWH / TRACKING KWH = (14860/17751) = 0.837 KWH SAVINGS

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