NATIONAL GRID USA SERVICE COMPANY

IMPACT EVALUATION
OF
2005 CUSTOM HVAC INSTALLATIONS – PART II

Executive Summmary

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Submitted to:

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Submitted by:

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1.0 Executive Summary

OVERVIEW

National Grid USA provides technical and financial assistance to commercial and industrial customers for equipment and building energy efficiency improvements through the Energy Initiative and Design 2000*plus* programs. "Custom" projects in these programs are customer- and site-specific and are justified as cost-effective using estimates of the projected energy and demand savings. Savings are estimated by comparing the proposed energy efficient equipment to the energy consumption of the existing equipment for retrofit projects or by comparing the proposed equipment to a baseline efficiency for new construction or replacement projects.

This report presents the results of an impact evaluation performed by Science Applications International Corporation (SAIC) of five Custom HVAC installations completed in 2005 under the two programs. These projects are among 15 projects in a sample of Custom HVAC installations included in the evaluation.

The report is organized into three sections. This executive summary presents an overview of the impact evaluation and summarizes results, conclusions and recommendations applicable to this and future evaluations. Section 2.0 contains an overview of instrumentation used at the sites along with specifications for the equipment. Finally, the comprehensive individual site reports are presented in the appendices.

OBJECTIVE

The objective of the impact evaluation is to provide verification or re-estimation of energy and demand savings for Custom HVAC projects for which incentives were paid in 2005. SAIC determined annual energy savings, summer coincident peak demand savings (diversified), winter coincident peak demand savings (diversified), and percent on-peak energy savings. Energy and demand savings were quantified for a sample of 15 sites so that National Grid can set appropriate financial incentive levels and eligibility criteria for future years, accurately predict energy and demand savings accomplished through the rebate programs, and demonstrate savings to regulators and other interested parties.

DESCRIPTION OF SAMPLE PROJECTS

Table 1-1 lists the five projects evaluated by SAIC along with a description of each project. The first three projects listed in the table are Energy Initiative (EI) applications while the remaining projects are Design2000*plus* (D2).

Table 1-1: Sample Projects

App. #	Program	Description of Project
119542	Energy Initiative	Modify Waterside Economizer Heat Exchanger: This measure proposed to reduce energy use and demand by increasing the capacity of an existing plate-and-frame heat exchanger (PFHE) used for waterside economizing in a 460,000 square foot office building from 500 to 650 tons and installing a new cooling tower to increase total cooling tower capacity and the hours of operation for the waterside economizer. The measure reduces mechanical cooling requirements from three water-cooled chillers having a total capacity of 900 tons that operate when the economizer is disabled.
504642	Energy Initiative	Optimized Condenser and Tower Water System: This measure proposed to reduce energy use and demand by upgrading a condenser water cooling system at a 191,000 square foot five-story office building to improve performance of the pumping systems as well as a water-cooled condensing unit, process chiller, and unitary water-source heat pumps. The condenser water system consists of an open two-cell cooling tower that is separated from the cooling systems by a plate-and-frame heat exchanger. A fouled plate-and-frame heat exchanger was cleaned to reduce pressure drop, flow requirements and pumping energy on the tower-side. Variable frequency drives (VFDs) were installed on pumps located on both the cooling tower and condenser water loops. Controls were provided to modulate tower water pump speed to maintain tower water temperature at setpoint and to control condenser water pump speed in response to differential pressure across the condenser water loop. Finally, the condenser water temperature setpoint is controlled at 70°F whenever possible. Previously, condenser water temperature was always maintained at 85°F. The efficiency of the cooling equipment without refrigerant head pressure control improves as the condenser water temperature drops.
505198	Energy Initiative	VAV Conversion: This measure proposed to reduce energy use and demand by converting ten (10) constant volume air handling systems serving a 360,000 square foot office building to variable air volume (VAV) and implementing various fan control strategies.
215324	Design 2000*plus*	Retrofit Fifth Floor HVAC to VAV – East, West and North Wings: This measure proposed to reduce energy use and demand by converting a portion of the fifth floor of a 598,500 square foot five-story commercial office building to variable air volume (VAV). Series fan powered VAV terminal boxes with electrically commutated motors were installed to serve interior core areas on the fifth floor. Primary air is delivered to the terminal boxes by central air handling units. The supply and return fan motors in the air handling units are equipped with variable frequency drives (VFDs) to control fan speed and flow in response to a duct static pressure control as terminal box primary air dampers modulate to meet space temperature setpoints.
508674	Design 2000*plus*	Install ECM (Electrically Commutated Motor) Fan Powered VAV Terminal Boxes: This measure proposed to reduce energy use and demand by installing 65 fan powered terminal boxes with electrically commutated motors (ECM) in a new 86,000 square foot two-story office building in lieu of standard constant speed fractional horsepower permanent split capacitor (PSC) induction motors. Primary air is delivered to the terminal boxes by a nominal 225 ton packaged evaporative air-cooled rooftop air conditioning unit (RTU). Secondary air is drawn into each terminal box from the ceiling plenum. The VAV boxes are equipped with electric reheat coils. Variable frequency drives (VFDs) modulate RTU supply and return air fan speed and flowrate in response to a traditional duct static pressure control as primary air dampers in the terminal boxes modulate. The rooftop unit includes two 40 hp supply air fans and one 50 hp return fan.

All of the measures were originally analyzed in Technical Assistance (TA) studies completed by technical assistance providers retained by National Grid. Custom spreadsheet or building energy simulation models were developed by the analysts to estimate energy and demand savings. For some projects, metered data were collected to help establish baseline operation.

EVALUATION APPROACH

The evaluation effort relied on site inspection of the measure, operation staff interviews, spot power measurements, field monitoring and data analysis. SAIC engineers performed the initial field work during the fall of 2006. Data loggers were installed on key systems affected by the energy conservation measures. Battery-powered time-of-use (TOU) data loggers were deployed to verify motor operating schedules if not available from other sources. Power meters or current recording data loggers were installed to capture load variations on specific motor applications. These data loggers were reserved for variable load applications on systems with the highest portion of project savings. When available, EMCS trend data collected by the customer were used for the evaluation analysis. Data collection occurred for a sufficient period of time to capture a range in loading conditions given the project schedule so that any seasonal variations could be observed.

The primary objective of this effort was to obtain sufficient data to provide a best estimate of actual energy and coincident peak demand savings for the measure. The evaluation was guided by a measurement and evaluation plan that was developed for the site prior to commencing field work. The plan specified data requirements for the measure and was developed from program documentation provided to SAIC including the program application, energy conservation report (i.e., Technical Assistance Study), Minimum Requirements Document (MRD), commissioning reports, and other miscellaneous support documentation and correspondence. The specific evaluation approaches defined in the work plan were refined during the site visit as required to account for actual field conditions and again after monitored data were analyzed along with supporting information gathered in the field.

Data collected in the field were analyzed to estimate annual energy and demand savings. On-peak energy and summer and winter coincident peak demand savings were estimated two ways to account for the current "new" calculation methodology defined by National Grid and to provide evaluation savings based on previous "old" definitions, which were applied to the tracking savings estimates when the Technical Assistance studies were prepared.

EVALUATION RESULTS

Tables 1-2 and 1-3 compare tracking and evaluation annual energy and diversified peak demand savings for the five projects in the sample. The percent of the total annual energy savings that occur during the on-peak period and the ratio of evaluation to tracking estimates of savings are also shown. The ratio of savings estimates, or realization rate, is listed as a percentage. The site-specific results presented in this report will be used in the sample of 15 evaluated sites to calculate case-weighted realization rates for each of the four savings parameters for the entire Custom HVAC program population.

For all five projects combined, evaluated annual energy savings are 93% of the tracking estimates[1]. Realization rates ranged from 54% for EI Application #119542 to 100% for EI Application #505198. When the new peak definitions are used, the total evaluation summer peak demand savings for the five sites are identical to the tracking estimate while total evaluated winter demand savings are 22% higher. Percent on-peak energy savings are 92% higher than tracking estimates when the new on-peak definitions are used (see Table 1-2). When the old definitions are applied to the evaluation, total summer and winter peak demand savings are 16 and 17% higher, respectively, and percent on-peak energy savings are 54% higher than tracking estimates (see Table 1-3).

[1] Comparisons between evaluation and tracking estimates of the sum of the savings for the five projects combined are not weighted to represent the population. Therefore, the realization rates presented in Tables 1-2 and 1-3 do not represent results for the population of Custom HVAC projects.

Table 1-2: Summary of Tracking and Evaluated Energy and Coincident Peak Demand Savings Based on New Peak Savings Calculation Methods for the Evaluation

App. #	Tracking Savings				Evaluated Savings				Evaluated/Tracking			
	Annual Energy (kWh)	% Energy On-Peak	Summer Peak kW	Winter Peak kW	Annual Energy (kWh)	% Energy On-Peak	Summer Peak kW	Winter Peak kW	Annual Energy (kWh)	% Energy On-Peak	Summer Peak kW	Winter Peak kW
EI-119542	326,412	39%	0	35.09	177,175	44%	0	93.99	54%	113%	N/A	268%
EI-504642	1,025,052	40%	114.93	113.05	1,004,958	47%	122.76	118.76	98%	118%	107%	105%
EI-505198	2,457,172	14%	189.18	181.96	2,462,724	44%	204.32	265.17	100%	314%	108%	146%
D2-215324	272,865	22%	14.60	56.30	151,380	71%	14.00	20.80	55%	323%	96%	37%
D2-508674	73,035	87%	46.91	18.03	46,714	88%	24.40	-3.70	64%	101%	52%	-21%
Total:	**4,154,536**	**24%**	**365.62**	**404.43**	**3,842,951**	**46%**	**365.48**	**495.02**	**93%**	**192%**	**100%**	**122%**

Table 1-3: Summary of Tracking and Evaluated Energy and Coincident Peak Demand Savings Based on Old Peak Savings Calculation Methods for the Evaluation

App. #	Tracking Savings				Evaluated Savings				Evaluated/Tracking			
	Annual Energy (kWh)	% Energy On-Peak	Summer Peak kW	Winter Peak kW	Annual Energy (kWh)	% Energy On-Peak	Summer Peak kW	Winter Peak kW	Annual Energy (kWh)	% Energy On-Peak	Summer Peak kW	Winter Peak kW
EI-119542	326,412	39%	0	35.09	177,175	34%	0	93.99	54%	87%	N/A	268%
EI-504642	1,025,052	40%	114.93	113.05	1,004,958	38%	126.87	115.27	98%	95%	110%	102%
EI-505198	2,457,172	14%	189.18	181.96	2,462,724	35%	248.30	253.06	100%	250%	131%	139%
D2-215324	272,865	22%	14.60	56.30	151,380	58%	16.00	19.00	55%	264%	110%	34%
D2-508674	73,035	87%	46.91	18.03	46,714	77%	32.41	-6.58	64%	89%	69%	-36%
Total:	**4,154,536**	**24%**	**365.62**	**404.43**	**3,842,951**	**37%**	**423.58**	**474.74**	**93%**	**154%**	**116%**	**117%**

Specific reasons for discrepancies between evaluation and tracking estimates of savings for each individual measure are presented in the site reports included in the appendix. Table 1-4 presents the primary reasons for differences between the evaluation and tracking estimates of annual energy savings.

Table 1-4: Primary Reasons for Discrepancies between Evaluation and Tracking Annual Energy Savings

App. #	Primary Reasons for Discrepancies Between Evaluation and Tracking Energy Savings
119542	*Modify Waterside Economizer Heat Exchanger:* Evaluated annual energy savings are 177,175 kWh, which is 149,237 kWh or 46% lower than the tracking estimate of 326,412 kWh. The primary reason for lost savings is that the monitored data collected for the evaluation showed that the waterside economizer was enabled only 34.1% of the hours below the current 28°F outdoor wet bulb switchover temperature observed over the monitoring period. Twenty-three percent of the cold hours were missed because the economizer wasn't enabled until the end of January; the other 43% of hours were lost due to mechanical cooling operation observed during hours below the wetbulb switchover temperature. Estimated savings were also lost because the observed 28°F outdoor wet bulb switchover temperature was less than the 39°F wet bulb (43°F dry bulb) switchover temperature predicted by the original TA. Evaluated winter demand savings are significantly higher than the tracking estimate largely because the evaluation baseline assumes mechanical cooling with no waterside economizer while the TA baseline assumed economizer cooling during the winter super peak hours.

App. #	Primary Reasons for Discrepancies Between Evaluation and Tracking Energy Savings
504642	*Optimized Condenser and Tower Water System:* Evaluated annual energy savings are 1,004,958 kWh, which is 20,094 kWh or 2% lower than the tracking estimate of 1,025,052 kWh. The individual components of the measure that contribute most to the difference in estimated savings and the reasons for the discrepancy in total savings are described below: ▪ *Condenser Water Pumps* – Condenser water pump savings are 10% higher than estimated because the evaluation assumed an average variable speed condenser water pump power of about 24 kW derived from monitored data, which is 7 kW higher than the tracking estimate of 31 kW. The same baseline constant speed/constant flow power of 86 kW was used in both the evaluation and TA Study. ▪ *Tower Water Pumps* – Tower water pump savings are 34% higher than estimated. The TA Study assumed constant 23 kW input power for the proposed pump. This compares to an average installed power of about 12.5 kW predicted by the evaluation analysis ▪ *Process Chiller CH-1* – The evaluation claims no energy or demand savings for this component of the measure, resulting in a loss of about 11% of the total estimated savings. Chiller CH-1 includes a head pressure control valve that the customer decided not to modify to allow head pressure to float with condenser water temperature as stated in the Minimum Requirements Document. The customer acknowledged that approval to modify the valve was not granted because of a concern that any chiller failure that might result would jeopardize cooling of the process equipment. ▪ *Condensing Unit WCCU-1* – The evaluation found that the condensing unit never operated during the monitoring period, which included ambient temperatures up to 82°F. However, about 25% of the estimated condensing unit savings are claimed by the evaluation based on the customer's assertion that it normally operates during the cooling season, but when it shuts down on a safety cutout it must usually be manually reset. Since occupants of the areas served by the unit reportedly fail to notice when the condensing unit is off line, it is not unusual for it to remain off for extended periods of time. ▪ *Water-Source Heat Pumps* – Evaluated savings are 64% less than the estimated WSHP savings due to higher than predicted condenser water temperatures. The TA Study assumes that entering water temperature would always remain at 70°F regardless of load or ambient conditions. SAIC found that although water temperature is controlled to about 70°F below 60°F outside air temperature, it increases as outside air temperature rises above 60°F. Therefore, installed heat pump compressor performance (i.e., kW/ton) actually degrades above this change point temperature as entering water temperature rises resulting in the reduction in evaluation savings for this component of the measure.
505198	*VAV Conversion:* While several of the fan control strategies were modified or not implemented, the overall annual energy savings estimated by the tracking analysis were achieved. Evaluated annual energy savings are essentially the same as the tracking estimate despite differences in start/stop schedules assumed for the VAV systems. The tracking analysis assumed that the VAV air handling systems would operate on a regular occupied mode schedule and would be shut down during unoccupied periods. However, the installed systems actually operate continuously, but at reduced fan speed during unoccupied mode periods. Fan power during unoccupied mode periods was typically very low, so the tracking assumption that the air handling systems would be shut down entirely did not have a significant impact on predicted savings. Further, the evaluated VAV systems operate in unoccupied mode approximately 113 hours per week compared to the tracking assumption that the systems would be shut down during unoccupied periods for about 80 hours per week. The additional 33 hours per week of unoccupied mode operation at low fan power levels for the evaluated systems help offset higher energy use from continuous operation. Tracking and evaluation results are in very close agreement with the exception of percent of annual savings that occur during the on-peak period. This may be the result of the tracking analysis assumption that the VAV systems would be shut down entirely during unoccupied mode periods, which would tend to shift more energy savings into off-peak periods. Higher evaluated on-peak energy savings are influenced by an earlier unoccupied mode start time for the installed VAV systems. Also, SAIC believes the tracking estimate of 14% on-peak energy savings could be incorrect. Output reports from the eQUEST/DOE-2.2 energy simulation models developed for the Technical Assistance Study show about 23% on-peak energy savings for the VAV conversion.

App. #	Primary Reasons for Discrepancies Between Evaluation and Tracking Energy Savings
215324	<u>*Retrofit Fifth Floor HVAC to VAV – East, West and North Wings*</u>*:* Evaluated annual energy savings are 151,380 kWh, which is 121,485 kWh or 45% lower than the tracking estimate of 272,865 kWh. Approximately 68% of the difference between the TA and evaluation estimates of annual energy savings is due to a difference in assumed baseline operation. The TA Study update includes a separate analysis that assumed the baseline makeup air unit would operate 12 hours per day and five days per week like the baseline fan coil units instead of operating continuously (8,760 hours per year) as reflected in tracking system savings. The evaluation found the alternate baseline to be more appropriate, so comparison of evaluation results to this alternate TA Study analysis is more valid. Evaluated annual energy savings are 39,462 kWh, or 21% lower than the TA Study estimate of 190,842 kWh for the alternate baseline condition. The most significant differences between the alternate baseline TA and evaluation models include system operating schedules and terminal box fan control. The TA provider assumed that the HVAC system would operate in the occupied mode 12 hours per day on weekdays only, or approximately 3,120 hours per year. The system actually operates weekdays, weekends, and holidays for about 5,592 hours per year. Also, the terminal box fans operate continuously on the same schedule as the main air handling units. The TA Study assumed terminal box fans would only operate on a call for heating. As a result of this assumption, the tracking estimate of savings may include roughly 30,000 kWh for terminal box fan savings alone that would not be available from the installed series fan powered boxes, which always operate in the occupied mode. The remaining difference between TA Study and evaluation energy savings is associated with predicted indirect savings.
508674	<u>*Install ECM (Electrically Commutated Motor) Fan Powered VAV Terminal Boxes*</u>*:* Evaluated annual energy savings are 46,714 kWh, which is 26,321 kWh or 36% lower than the tracking estimate of 73,035 kWh. The difference in evaluation and tracking savings is due to differences in baseline PSC terminal box fan power and HVAC system operating schedules. The reduction in average fan power between the baseline constant speed/constant power PSC terminal box fans and installed variable speed ECM terminals is 25.1 kW for the evaluation and 34.6 kW for the TA Study analysis. Despite a 27% reduction in evaluation fan power savings relative to the tracking analysis, evaluation energy savings for the terminal box fans only are 26% higher than TA Study savings because of the 70% increase in actual annual operating hours compared to the TA prediction (5,160 vs. 3,012 hours). The longer operating hours increases terminal box fan savings proportionally, and also affects mechanical cooling savings and electric reheat penalties during those additional hours of operation. The impact on electric reheat energy requirements is especially significant. Evaluation electric reheat annual energy use is approximately twice the TA estimate. In addition to the interactive effect the reduction in fan heat has on increasing reheat energy requirements, the increased HVAC system operation and extension of the occupied mode period accounts for the remaining difference between evaluation and tracking estimates of reheat energy use.

CONCLUSIONS AND RECOMMENDATIONS

Differences between tracking and evaluated savings can be explained mostly by the availability of monitored data for the impact evaluation and a better understanding of how the installed systems are actually operated and controlled. When the TA provider did not have the benefit of monitored data or spot measurements of power to help them establish baseline conditions, they typically relied on design data for specific measures for model input as well as site surveys and customer interviews, so differences in savings estimates is expected. Also, installed systems often differ in equipment and/or operation than described in the TA Study for the proposed measure.

The following process-related recommendations should be considered by National Grid to improve future estimates of savings for proposed Custom HVAC measures and to help ensure savings persist for completed projects:

1. Require more comprehensive measure and baseline descriptions for the TA studies. Measure descriptions in particular were in some cases too general. We recommend that the make, model, ratings, quantities, performance characteristics, etc. for the basis of design be provided in the report

for each measure when available. A more complete description of each measure and its baseline would simplify the evaluation process, particularly when investigating reasons for differences in savings estimates.

2. Request a clear description of the analysis approach including how savings were calculated, underlying assumptions, etc.

3. Gather as much metered data as possible and practical to support the savings analysis. This was done for some of the evaluated projects, which helped establish the baseline and improve confidence in evaluation savings estimates.

4. When program-related commissioning is required, consider more extensive functional performance testing of systems affected by the measures. Proper operation is verified by observing the response of a controlled device immediately after setpoints are changed or point values overridden (through an EMCS). Since many of the observations made during functional testing are “point-in-time”, we recommend collecting EMCS trend data to provide information on how systems operates over time. For example, trending VFD speed on fans and pumps provides insight into their variability. Data collected can be imported into a spreadsheet application so the data can be manipulated and graphs produced to make trends more apparent and help diagnose system operation.

5. The evaluation plan for several sites in the sample assumed that the customer would be able to collect EMCS trend data over the course of the evaluation monitoring period. However, only one of the five sites was able to provide comprehensive trend data. National Grid should encourage customers who participate in future impact evaluations to better support the evaluation effort, with a particular emphasis on the importance of trend data.