ENGINEERING ESTIMATES VS. IMPACT EVALUATION RESULTS: HOW DO THEY COMPARE AND WHY?

Steven M. Nadel[1]
Kenneth M. Keating[2]

[1]American Council for an Energy-Efficient Economy
1001 Connecticut Avenue NW, Suite #801
Washington, DC 20036

[2]Bonnevile Power Administration
Post Office Box 3621-RPEB
Portland, OR 97208

1991

ENGINEERING ESTIMATES VS. IMPACT EVALUATION RESULTS: HOW DO THEY COMPARE AND WHY?

Steven M. Nadel
American Council for an Energy-Efficient Economy
Washington, DC

Kenneth M. Keating
Bonneville Power Administration
Portland, OR

Introduction

For most energy efficiency programs in operation today, the only estimates of energy savings available are based on engineering calculations. For example, energy savings for an insulation program may be estimated through heat loss calculations, or savings for a lighting program may be estimated by multiplying watts displaced times assumed annual operating hours. However, for some programs, "impact evaluations" have been conducted in which actual energy savings are estimated by conducting statistical analysis on metered consumption data. A major question that has faced program managers and evaluators for many years is, "How do the engineering estimates compare to the impact evaluation results?"

In asking this question, it is important to keep in mind that impact evaluation results are also estimates. Depending on procedures used in the evaluation and judgement calls made by the evaluator, different impact evaluation results can be obtained from the same set of data. However, because impact evaluations generally are based on a careful comparison of energy use before and after program participation and control for energy use changes not attributable to the program, they usually produce "better" estimates of program savings than engineering calculations.

This paper examines the results of 42 impact evaluations conducted by electric utilities on specific conservation programs. Evaluations of gas and oil conservation programs, and of electric load management programs are not discussed in this paper. For each program, engineering estimates are compared to the results of the impact evaluation and explanations for any discrepancies found are discussed. Programs examined fall into five categories:

1. Residential retrofit
2. Residential appliances and equipment
3. Residential new construction
4. Commercial retrofit
5. Other (commercial new construction, and industrial and agricultural retrofit)

This paper then discusses general patterns that emerge from the analysis and concludes with a few guidelines for program planners and managers.

In reviewing the results summarized in this paper, it is useful to keep a number of points in mind. Unless otherwise noted, all of the impact evaluations discussed in this paper are based on statistical analyses of billing data for program participants compared to control groups of nonparticipants. Impact evaluation results are reported on a net basis -- net of changes in energy use by the control group. We focus on net savings, because net savings are the critical variable in measuring the effectiveness of demand-side management programs. Also, unless otherwise noted in the text, engineering estimates are based on data collected on individual participants. For a few programs, engineering estimates were calculated during the program planning stage, before participants were identified. To the extent that actual participants differ from assumptions made during the program planning stage, these "planning stage estimates" will be inaccurate.

Traditionally, engineering estimates have been used to measure gross savings (without adjustment for control group effects) on a building-specific basis. The use of engineering calculations to estimate net savings for programs requires modifications to traditional engineering approaches, such as incorporating adjustment factors to reflect best estimates of what would happen in the absence of a program. Since incorporating these adjustments is a new and evolving practice, many of the engineering estimates discussed in this paper did not incorporate these adjustments. While it may seem unfair to judge engineering estimates of gross savings by comparing them to impact evaluations of net savings, given the importance of net savings for determining program impacts and program cost-effectiveness, we chose to make the comparison, in an effort to encourage program planners and implementers to devote increased attention to estimating the net impacts of programs.

Residential Retrofit Programs

Residential retrofit programs generally emphasize weatherization improvements to homes with electric space heat, although measures to reduce electricity use for other end uses are often encouraged as well. In our research we found 11 residential retrofit programs for which both engineering estimates and impact evaluation results are available. Basic information on each of the programs, including the ratio of savings estimated with engineering estimates to savings estimated in the impact evaluation, is summarized in Table 1.

Table 1. Summary Information on Residential Retrofit Programs

Program	Program Description	Engineering/ Impact	Reference
CMP Energy Management Assistance	Low-income grants	40%	7
CMP Pay As You Save	Utility grant and loan	47%	7
CMP Energy Management Rebates	Rebates	15%	7
CMP Packaged Weatherization	Standard weatherization package	36%	7
CMP Weathershield	Low-income grants	22%	33
GPU RECAP	Performance contracting	22-44%	2
NU Performance Contracting	Performance contracting	22%	24
BPA Residential Weatherization	Comprehensive weatherization	40-58%	36
Hood River Conservation Project	Comprehensive weatherization	43%	13
SCL HELP (multiplex)	Comprehensive weatherization	117%	4
NEES Partners - Residential	Comprehensive weatherization	107%	15

As is shown in this table, savings estimated with an impact evaluation ranged from 15-117% of the engineering estimates. For every program but two, the impact evaluation results were less than the engineering estimates. For the first four Central Maine Power (CMP) programs, the low savings in the impact evaluation were attributed to the use of secondary fuels. That is, for many homeowners, the energy improvements displaced wood and other secondary fuels, and reductions in electricity use were limited. In addition, CMP hypothesizes that the engineering estimates may have been overly optimistic, or that changes occurred in the participating households that were not captured in the analysis (Ref. 7). For the CMP Weathershield/Attic Attack program, the low savings were attributed to inaccuracies in the assumptions used to calculate the engineering estimates (these estimates were compiled at the time of program planning, and included no data on the specific homes being weatherized), and to possible problems in material selection, installation, and inspection (Ref. 33).

Problems with material and installation quality were found to be a major reason for low savings in the Northeast Utilities (NU) Performance Contracting Program. In addition, the formulas used for the engineering estimates were found to include factors that should have been excluded (e.g., conservation actions resulting from concurrent participation in other programs) and to exclude factors that should have been included (Ref. 24). No explanation for the less-than-expected savings in the General Public Utility (GPU) RECAP program was provided in the evaluation report (Ref. 2).

The discrepancy between engineering estimates and impact evaluation results was investigated extensively for the Bonneville Power Administration (BPA) Residential Weatherization Program and the companion Hood River Conservation Project. In both cases, as with the CMP programs, use of secondary fuels contributed to the lower than expected savings. In addition, the engineering estimates were based on prototype buildings and did not consider how much energy the buildings were actually using and could not account for a variety of building/occupant interactions, such as rooms that were not heated or were only partially heated, actual thermostat settings, or window coverings. In addition, for the Residential Weatherization Program, net savings (net of a control group of nonparticipants) were reduced because control group houses also implemented some conservation measures due to significant rate increases during the period of analysis (this finding does not apply to the Hood River Project, which eliminated the control group from the final analysis due to problems with the control group selected). It should be noted that initial analyses of the Hood River Project reported that customers tended to set their thermostats slightly higher after the weatherization than before, thereby "taking back" some of the savings in the form of improved comfort (Ref. 13). However, subsequent detailed analysis found that thermostat settings following weatherization were essentially the same as pre-weatherization settings (Ref. 34).

Impact evaluations of the BPA program also show some interesting trends in terms of the persistence of energy savings. For the BPA program, savings were measured for one, two, and three years after weatherization. For example, for homes weatherized in 1986, impact evaluation results were 58% of engineering estimates in the first year after weatherization, but only 40% in the third year after weatherization (an average drop of approximately 15% per year). This drop was due to weatherization measures wearing out and slow adoption of weatherization measures by program nonparticipants (which reduces the net savings attributable to the program). For homes weatherized in 1985 and earlier years, savings also declined in the second and third years after weatherization, with the decline ranging from less than 1% per year to nearly 20% per year, depending on the cohort being analyzed (Ref. 36).

In two cases, impact evaluation results were slightly higher than the engineering estimates -- the Seattle City Light (SCL) Home Energy Loan Program (HELP) for multiplex (2-4 unit) buildings and the New England Electric System (NEES) Partners in Energy Planning Residential Program. For the SCL program, engineering estimates were calculated for program planning purposes, and were not based on home-specific data. Thus, to the extent homes actually participating in the program deviate from pre-program assumptions, the engineering estimates and impact evaluation results will differ. Also, the analysis excluded apartments that were vacant a significant amount of time (most of the apartments were rental units). Since savings are likely to be low during vacant periods, excluding vacant units inflates the results of the billing analysis (Ref. 4).

For the NEES program, while impact evaluation savings were slightly higher than the prior engineering estimates, the difference was small and unlikely to be statistically significant. For this program, engineering estimates were done on a house-specific basis, including estimating infiltration losses with the aid of a blower door. In addition, this program had a high degree of quality control over the measure installation process. Furthermore, since this was a pilot program undertaken for research purposes, homes using secondary fuels were excluded from the program, thereby eliminating a potential source of lost savings (Ref. 15).

In summary, for most of the residential retrofit programs for which impact evaluations and engineering estimates are available, impact evaluation results are substantially less than the engineering estimates. Reasons for the discrepancies include use of secondary fuels, optimistic assumptions used in the engineering estimates, and quality control problems in measure installation. However, the results of the NEES program illustrates that by combining careful audit and quality control procedures, it may be possible to bring engineering estimates and impact evaluation results into balance.

Residential Appliance and Lighting Programs

In our research we found nine residential appliance and lighting programs for which both engineering estimates and impact evaluation results are available. These include two refrigerator rebate programs, one refrigerator turn-in program (in which old, operating refrigerators are picked by the utility in order to reduce the number of second refrigerators in use), two air conditioner rebate programs, three water heater wrap programs (which install water heater blankets, low flow showerheads and aerators, and other water conservation measures), and one compact fluorescent lamp installation program. Information on each of these programs is summarized in Table 2.

Table 2. Summary Information on Residential Appliance and Lighting Programs

Program	Engineering/Impact	Reference
WEPCo Refrigerator Rebate	122%	27
MECo Pilot Refrigerator Rebate	34	21
WEPCo Refrigerator Turn-in	105	27
WEPCo Central A/C Rebate	negative	27
WEPCo Room A/C Rebate	negative	27
CMP Bundle-up (water heater retrofits)	60-74	8
Hood River Conservation Project (water heater retrofits)	67-101	1
NEES Water Heater Wrap	62	22
NEES Energy Fitness (compact fluorescents)	43	10

For the nine residential appliance and lighting programs included in Table 2, impact evaluation results ranged from negative savings to 122% of the engineering estimates.

For the two Wisconsin Electric Power Company (WEPCo) refrigerator programs, impact evaluation results were slightly higher than the engineering estimates (Ref. 27). This difference may be due to overcompensating for the impact of free riders in developing the engineering estimates. For the Massachusetts Electric Company (MECo) refrigerator rebate program, savings per unit were very low (annual savings of less than 50 kWh per home), and so the discrepancy between the engineering estimates and the impact evaluation were only 25 kWh/year -- a meaningless difference when analyzing whole-house consumption records (Ref. 21).

In contrast to their results with refrigerators, WEPCo found that engineering estimates and impact evaluation results differed substantially for air conditioner rebate programs. In fact, homes participating in the air conditioner rebate programs actually increased their energy consumption (Ref. 27). The author postulates that purchasers of efficient air conditioners may operate their air conditioners more often than customers who were not told that their air conditioners are efficient. This tendency is more likely to apply in moderate climates, such as Wisconsin, where air conditioners operate only a limited number of hours each year, and where use of air conditioning is considered discretionary.

Impact evaluations of the three water heater retrofit programs showed impact evaluation results ranging from 60-101% of engineering estimates. For the Central Maine Power (CMP) Bundle-up program, impact evaluation results were approximately 65% of the engineering estimates. The primary reason for the discrepancy was that the engineering estimate assumed that all five program measures were installed in all homes (Ref. 8), when in reality, a typical program of this type installs each individual measure in 50-80% of participating households (Ref. 1). Another significant reason for the discrepancy was that assumptions used in the engineering estimates, such as average family size and water heater temperature setting, were found to be inaccurate. Furthermore, the evaluators postulate that some measures may have been removed, or that some of the savings from low-flow showerheads were "taken back" in the form of higher water temperatures or longer showers (Ref. 8).

For the NEES Water Heater Wrap program, impact evaluation results were only 62% of the engineering estimates (this evaluation did not include a control group). A comparison of homes that received only water heater wraps to homes that received a package of wraps, low-flow showerheads and faucet aerators indicates that most of the savings achieved were attributable to the wraps. The author of the report hypothesizes that much of the difference between the engineering estimates and the impact evaluation results was due to homeowners who removed their low-flow showerheads, or took longer showers after the new showerheads were installed (Ref. 22).

For the water heating components of the Hood River Conservation Project, engineering estimates were reported as a range, and impact evaluation results fell within this range. This study involved submetering of electric water heaters, which allowed detailed analysis of individual retrofit measures. Interestingly, the impact evaluation found that savings from water heater wraps were greater than expected, while savings from pipe wraps and low-flow showerheads were less than expected. Explanations for the discrepancies are not provided in the evaluation report (Ref. 1), although savings from pipe wraps were small enough that the difference between the impact evaluation results and the engineering estimates may not be statistically significant.

Impact evaluation results are available for only one residential lighting program -- the NEES Energy Fitness program. Results to date are only preliminary, and show that impact evaluation results are approximately half of the engineering estimates. Reasons for the discrepancy are now being investigated, but are likely to include: (a) the engineering estimates, which were based on resident self-reports, overestimated lamp operating hours, (b) compact fluorescent lamps operate for more hours than the incandescent lamps which were replaced, because the large efficiency gain achieved by the compact fluorescents makes residents less concerned about lamp operating costs, and (c) some of the compact fluorescent lamps were removed by participants (Ref. 10).

In summary, the limited data available indicate that engineering estimates for refrigerator rebate and turn-in programs can be accurate when free rider rates are correctly estimated and that savings from water heater wraps may be greater than some engineering estimates predict. However, savings from air-conditioner rebates, low-flow showerheads and compact fluorescent lamps may be reduced by a "take-back" effect.

Residential New Construction Programs

Impact evaluation results are available for two residential new construction programs. Both programs specify construction standards for efficient homes -- standards which significantly exceed building code requirements. In both cases, impact evaluations compared the energy efficiency of participant houses to typical non-participant houses that were built at the same time as the participant houses. Information on these two programs is summarized in Table 3.

Table 3. Summary Information on Residential New Construction Programs

Program	Engineering/Impact	Reference
Southwest Public Service Energy Efficient Homes	108-131%	9
CMP Good Cents	50-105%	25

For the Southwest Public Service program, savings are slightly greater than the engineering estimates. No explanation for the higher than expected savings is provided (Ref. 9). For the Central Maine Power program, impact evaluation results are slightly higher than engineering estimates when the engineering estimates are based on detailed home specific calculations for both the participant and non-participant homes (Ref. 25). However, when impact evaluation results are compared to pre-program engineering estimates, the impact evaluation results are approximately half the engineering predictions. The likely reason for the discrepancy was that the state building code was amended (with the active support of CMP), which substantially increased the efficiency of non-participant homes (Ref. 19).

In summary, while one cannot generalize from only two studies, it appears that when careful and detailed engineering estimates are calculated for both participant and non-participant homes, these estimates can be in fairly close agreement with impact evaluation results. However, when engineering estimates do not capture efficiency improvements in non-participant homes, impact evaluation results will be lower than engineering predictions.

Commercial Retrofit Programs

In our research we found evaluations of 14 commercial retrofit programs or program components which included both engineering estimates and impact evaluations results, including two audit program studies, three studies on institutional building programs (for schools, hospitals, and government buildings), four rebate program studies, two comprehensive program studies (for programs where the utility provides not only financial incentives, but also audits and assistance arranging measure installation), and three direct installation program studies (for programs where the utility installs eligible measures). In some cases industrial facilities were also eligible to participate in these programs, although industrial facilities generally represent only a small proportion of program participants. Information on each program is summarized in Table 4.

Table 4. Summary Information on Commercial Retrofit Programs

Program	Program Type	Engineering/ Impact	Reference
Central Hudson Easy Savers	Audit	88%	14
SDG&E Non-Residential Audit	Audit	83-98	26
BPA Institutional Buildings	Institutional	60	16
WA Institutional Buildings	Institutional	69-82	6
WA Institutional Buildings	Institutional	58-72	18
SCE Hardware Rebate	Rebate	96	35
BPA CIPP Rebate (small)	Rebate	36	3
BPA CIPP Incentive (large)	Comprehensive	109	3
SCL CIPP Rebate (small)	Rebate	49	5
SCL CIPP Incentive (large)	Comprehensive	103	5
MECo E-Zone Small C&I (small)	Direct install	44	23
MECo E-Zone Small C&I (medium)	Direct install	248	23
NEES Rhode Island Small C&I	Direct install	59	20
NEES Energy Initiative (lighting)	Rebate	51-61	11

As can be seen in this table, impact evaluation results for commercial retrofit programs range from 36% to over 200% of engineering estimates.

For the two audit programs, impact evaluation results are close to the engineering estimates. For the Central Hudson Easy Savers program there was a 12% discrepancy between the impact evaluation and the engineering estimates -- a discrepancy that is attributed to errors in some of the engineering assumptions, and to differences between customers' self-reports of operating parameters such as operating hours, and actual operating conditions (Ref. 14). For the San Diego Gas and Electric Non-Residential Audit program, the impact evaluation estimates of kWh savings were 17% less than the engineering estimates, while the kW savings were only 2% less. The small difference between the engineering estimates and the impact evaluation was attributed to inaccuracies in the engineering estimates, and to a possible "take-back" effect (evidence for the former was found, but the latter was only hypothesized) (Ref. 26).

For the three institutional building programs, impact evaluation results range from approximately 60% to approximately 80% of the engineering estimates. All three of these evaluations were done on BPA's Institutional Buildings program, so general agreement between these studies is to be expected. None of these studies included a control group, so the difference between the engineering estimates and the impact evaluation could be due to factors not related to the program. For example, Kunkle found that when impact evaluation results were adjusted for known changes in each facility, the evaluation results averaged 72% of the engineering estimates, while when the adjustments were not made, the impact/engineering ratio dropped to 58%. In addition, he found that differences between the impact evaluation and the engineering estimates could be explained at least partially by two other factors: (a) overestimating the hours of operation for lights (which causes estimated lighting savings to be too high), and (b) inadequate maintenance of some measures, particularly control systems, HVAC improvements, and other measures that require the regular attention of maintenance personnel (Ref. 18). It should be noted that evaluations of oil and gas savings from the U.S. Department of Energy's (DOE's) Institutional Conservation Program (a program very similar to BPA's program), found similar discrepancies between engineering and impact evaluation estimates (Ref. 28).

The other nine commercial retrofit program evaluations we examined fall into two categories -- five programs for which the impact evaluation results were significantly less than the engineering estimates, and four for which the impact evaluation results were equal to or greater than the engineering estimates.

The five programs where impact evaluation results were less than expected were all programs emphasizing lighting improvements, including four programs which targeted small commercial buildings (electricity use less than 48-240 MWh/year, depending on the program). For these programs a number of problems were observed. For example, low savings in the rebate component of the BPA Commercial Incentive Pilot Program (CIPP) were found to be attributable to disconnected measures, incorrect engineering assumptions, and increased use of electric heat in buildings to make up for the lost heat output of inefficient lamps (Ref. 3). (This last factor is primarily an issue in regions with high electric heating loads and low cooling loads.)

Low savings among small buildings in the Massachusetts Electric Co. (MECo) Enterprise Zone Small C&I Program were attributed to two causes: (a) the engineering estimates overestimated lighting system operating hours, and (b) the direct installation program replaced some burned-out lamps and ballasts with new working units, thereby increasing energy use (and lighting levels) (Ref. 23).

Preliminary results from the NEES Rhode Island Small C&I program indicate that the discrepancy between engineering estimates and the impact evaluation may be due to four factors: (a) customers overestimating the number of hours each lighting fixture is used, (b) removal of measures in some cases, (c) replacement of burned-out lamps and ballasts with new working units, thereby increasing energy use, and (d) underestimating the energy consumption of the baseline system existing prior to retrofit in some cases (Ref. 20).

Impact evaluation results for the NEES Energy Initiative program, a rebate program for lighting, motor, and other conservation measures, are also preliminary. Explanations for the lower-than-expected savings are now being sought. Among the likely explanations are (a) errors in rebate applications that tended to exaggerate the expected savings, and (b) errors in recording the work completion date that shifted several months of data in the billing analysis from the post-retrofit period to the pre-retrofit period (this lowered pre-retrofit period estimates of energy use, thereby lowering savings calculated in the impact evaluation) (Ref. 11).

The four programs where impact evaluation results were equal to or greater than expected values generally served medium and large customers (annual electricity use greater than about 200 MWh). For the Southern California Edison Hardware Rebate, on average, impact evaluation results and engineering estimates were about equal (Train and Ignelzi). For the other three programs, impact evaluation results actually were greater than engineering estimates. Only one of the evaluation reports posited an explanation for this finding; in medium-sized buildings served by the MECo Enterprise Zone program, the greater than expected savings were attributed to savings in cooling loads resulting from reduced heat gains from lights following the lighting system efficiency improvements. The engineering estimates did not include an adjustment for this factor (this factor becomes an issue in buildings with high cooling loads and low use of electricity for heating -- situations that were found to be more prevalent in medium-sized buildings than in small buildings). Also, due to the small number of medium-sized buildings included in the sample, the impact evaluation results may be subject to a wide margin of error (Ref. 23).

In summary, available evaluation work on commercial retrofit programs indicates that impact evaluation results tend to be less than engineering estimates for lighting programs directed at small buildings, and for the BPA and DOE Institutional Buildings programs. For most other programs, engineering estimates and impact evaluation results were found to be in reasonably close agreement, and in some cases impact evaluation results can be greater than engineering estimates.

Other Programs

In our research we found six other evaluation reports relevant to the topic at hand, including one study on a commercial new construction program, four studies on an industrial retrofit program, and one study on an agricultural retrofit program. Information on each of these programs is summarized in Table 5.

Table 5. Summary Information on Commercial New Construction, Industrial Retrofit, and Agricultural Retrofit Programs

Program	Program Type	Engineering/Impact	Reference
BPA Energy Edge	New construction	72%	12
BPA Energy Savings Plan	Industrial		
Lamb-Weston		118%	32
SDS Lumber		124-149%	29
ITT Rayonier		42%	30
Bellingham Cold Storage		76%	31
BPA Irrigated Agriculture	Agricultural	114-117%	17

For the one commercial new construction program we examined, impact evaluation results relative to a control group were approximately 28% less than engineering estimates. These results are considered preliminary and subject to change. In the evaluation report, the discrepancy is attributed to quality control problems during construction and to inadequate attention to the commissioning and debugging of some measures, such as control systems (Ref. 12).

Four impact evaluation reports have been prepared for the BPA Energy Savings Plan program for industrial customers. Each report addresses a specific change to an industrial process implemented by a specific customer (customer specific evaluations were done because of the magnitude of the savings achieved by each customer, and because each process and measure requires a different evaluation procedure). Each report is based on extensive monitoring and engineering work at the individual facilities. For half of the studies impact evaluation results were higher than engineering estimates, while for the other half the reverse held true. On average, engineering estimates and impact evaluation results were approximately equal. Reasons for the discrepancy were highly site-specific, and included errors in the engineering estimates, increased flow requirements (resulting in increased savings), undersizing of equipment (requiring the addition of an additional piece of equipment, which cut into the energy savings), and the fact that one control system had yet to be fully hooked up (Ref. 29, 30, 31, and 32).

Finally, for the one agricultural program we examined, the BPA Irrigated Agriculture program, impact evaluation results were slightly higher than the engineering estimates. The two estimates were in close agreement in large part because the engineering estimates were based on measurements of the pump load, before and after retrofit. Due to the site-specific, pre-post measurements employed, there was little room for the two estimates to vary (Ref. 17).

Discussion

In the preceding analysis, a number of trends emerge which provide insight into the relationship between impact evaluation results and engineering estimates. Examination of these trends provides useful information for program planners on how to most accurately estimate the likely impacts of programs. Still, many program-specific factors affect the relationship between engineering estimates and impact evaluations, so a review of these trends is not a substitute for performing impact evaluations on each and every program.

Important trends which emerge from the data are as follows:

1. Results to date indicate that impact evaluation results often are lower than engineering estimates for residential retrofit programs, commercial and residential lighting programs directed at small customers, and for low-flow showerheads. For residential appliance and new construction programs, and multiple-measure C&I retrofit programs directed at large customers, on average, engineering estimates and impact evaluation results have been similar.

2. Where engineering estimates and impact evaluation results differ, a number of common explanations emerge: (a) erroneous assumptions in the engineering estimates (particularly over-estimating lighting system operating hours); (b) complex interactions which could have been modeled in the engineering estimates, but were not (examples include use of secondary fuels, rooms that are unheated or only partially heated, the effect of lighting system changes on heating and cooling loads), and "take-back" effects for some measures (air conditioner rebates in moderate climates, low-flow showerheads, and residential compact fluorescents); (c) quality control problems during measure installation, commissioning, and maintenance; and (d) greater than expected adoption of conservation measures by non-participating customers, which lowers the net savings attributable to a program.

3. Even for program types where discrepancies between engineering estimates and impact evaluation results are common, several programs have achieved close agreement between the two estimates. In general, close agreement is most likely when: (a) engineering estimates are based on accurate assumptions collected at the participant specific level (in many cases site-specific measurements are required); (b) engineering estimates include adjustments for complex interactions which affect the actual savings achieved (discussed above); and (c) procedures to ensure good quality control are in place for the installation, commissioning, and maintenance phases of each project.

Acknowledgements

Support for this work was provided in part by a grant from the John D. and Catherine T. MacArthur foundation.

References

(1) Brown, Marilyn, et al., Impact of the Hood River Conservation Project on Electricity Use for Residential Water Heating, ORNL/CON-238. Oak Ridge, TN: Oak Ridge National Lab, 7/87.

(2) Brown, Marilyn and Dennis White, *Impact Analysis of a Residential Energy Conservation Shared Savings Program: The General Public Utilities Experience*, ORNL/CON-217. Oak Ridge, TN: Oak Ridge National Laboratory, 2/87.

(3) Cambridge Systematics, *Evaluation of the Commercial Incentives Pilot Program, Final Impact Evaluation Report.* Portland, OR: Bonneville Power Administration, 8/90.

(4) Coates, Brian, *Energy Savings for Multiplex Dwellings in the Home Energy Loan Program.* Seattle, WA: Seattle City Light, 11/88.

(5) Coates, Brian, *Energy Savings and Cost-Effectiveness in the Commercial Incentives Pilot Program.* Seattle, WA: Seattle City Light, 1991.

(6) Davis, Robert, *The Institutional Buildings Program in Washington: An Analysis of Program Impacts.* Olympia, WA: Washington State Energy Office, 12/87.

(7) Ecker, Linda and Leona Michelsen, "Comparative Analysis of the Effect of Incentives on Weatherization Programs." Augusta, ME: Central Maine Power, 8/89.

(8) Ecker, Linda, Michael Parti, and Monica Dion, "A Comparison Study of Energy Savings Methodologies," *Demand-Side Management Strategies for the 90s, Proceedings: Fourth National Conference on Utility DSM Programs*, CU-6367. Palo Alto, CA: Electric Power Research Institute, 4/89. Pp. 46-1 - 46-8.

(9) Gage, James, and James Niewald, "This New House: An Evaluation of a Utility Sponsored New Home Program," *Demand-Side Management Strategies for the 90s, Proceedings: Fourth National Conference on Utility DSM Programs*, CU-6367. Palo Alto, CA: Electric Power Research Institute, 4/89. Pp. 57-1 - 57-10.

(10) Granda, Chris, personal communication. Westborough, MA: New England Electric, 5/91.

(11) Hamilton, Karen, personal communication. Westborough, MA: New England Electric, 5/91.

(12) Harris, Jeffrey, et. al., *Energy Edge Impact Evaluation, Findings and Recommendations from the Phase One Evaluation.* Berkeley, CA: Lawrence Berkeley Lab, 5/90.

(13) Hirst, Eric, *Cooperation and Community Conservation, Final Report, Hood River Conservation Project*, DOE/BP-11287-18. Portland, OR: Bonneville Power Administration, 6/87.

(14) Hoch, Lance, et. al., *Evaluation of the Easy $avers Program.* Poughkeepsie, NY: Central Hudson Gas & Electric, 3/90.

(15) Jacobson, David, et. al., "One Utility's Experience in Designing and Implementing a Demonstration Retrofit Program for Electrically Heated Homes," overhead transparencies presented at the ACEEE Summer Study, Pacific Grove, CA, 8/31/90. Westborough, MA: New England Electric.

(16) Keating, Kenneth, and Susan Blachman, "In Search of an Impact: An Evaluation of an Institutional Buildings Program," *Energy Conservation Program Evaluation, Practical Methods, Useful Results, Proceedings*

of the 1987 Conference, Volume 1. Argonne, IL: Argonne National Laboratory, 8/87. Pp. 107-116.

(17) Keating, Kenneth, Bruce Harrer, and Jack Tawil, "Turning Over New Ground: An Impact Evaluation of an Irrigated Agriculture Program," *Energy Conservation Program Evaluation, Practical Methods, Useful Results, Proceedings of the 1987 Conference, Volume 2.* Argonne, IL: Argonne National Laboratory, 8/87. Pp. 41-50.

(18) Kunkle, Rick, "Case Study Analysis of the Institutional Buildings Program in Washington State," *Energy Conservation Program Evaluation: Conservation and Resource Management, Proceedings of the August 23-25, 1989 Conference.* Argonne, IL: Argonne National Lab. Pp. 303-308.

(19) Michelsen, Leona, personal communication. Augusta, ME: Central Maine Power, 4/91.

(20) Miller, Meredith, personal communication. Westborough, MA: New England Electric, 5/91.

(21) Mystakides, Elizabeth, "The Massachusetts Electric Refrigerator Rebate Program: Accomplishments and Planning Guides," *Proceedings of the 1988 ACEEE Summer Study on Energy Efficiency in Buildings, Volume 9, Program Evaluation.* Washington, DC: American Council for an Energy-Efficient Economy, 8/88. Pp. 9.109-9.121.

(22) Mystakides, Elizabeth, "Water Heater Wrap Program, Draft Evaluation" Westborough, MA: New England Electric, 1989. Also personal communication with the author, March, 1991.

(23) Nadel, Steven and Malcolm Ticknor, "Electricity Savings from a Small C&I Lighting Retrofit Program: Approaches and Results," *Energy Conservation Program Evaluation: Conservation and Resource Management, Proceedings of the August 23-25, 1989 Conference*, Argonne, IL: Argonne National Laboratory. Pp. 107-112.

(24) Peach, H. Gil, *Evaluation of Western Massachusetts Electric Company Residential Sector Performance Contracting Pilot Program.* Hartford, CT: Northeast Utilities, 3/89.

(25) RCG/Hagler, Bailly, Inc., *Evaluation of the Energy Savings Resulting from Central Maine Power Company's Good Cents Home Program.* Augusta, ME: Central Maine Power, 11/90.

(26) Regional Economic Research, Inc., *SDG&E Non-Residential Audit Evaluation, Final Report.* San Diego, CA: San Diego Gas & Electric, 2/91.

(27) Rogers, Eric, "Evaluation of a Residential Appliance Rebate Program Using Billing Record Analysis," *Energy Conservation Program Evaluation: Conservation and Resource Management, Proceedings of the August 23-25, 1989 Conf.*, Argonne, IL: Argonne National Lab. Pp. 263-269.

(28) Schueler, Vincent, "Measuring the Impacts of Energy Efficiency Measures in Institutional Buildings with Billing Data: A Review of Methodological Issues," *Proceedings ACEEE 1990 Summer Study on Energy Efficiency in Buildings, Volume 6, Program Evaluation.* Washington, DC: American Council for an Energy-Efficient Economy, 8/90. Pp. 9.155-9.166.

(29) Spanner, G.E., and D.R. Dixon, "Letter Report, Impact Evaluation of an Energy $avings Plan Project at Gorge Energy Division of SDS Lumber." Portland, OR: Bonneville Power Administration, 3/89.

(30) Spanner, G.E., and D.R. Dixon, "Letter Report, Impact Evaluation of an Energy $avings Plan Project at ITT Rayonier." Portland, OR: Bonneville Power Administration, 8/90.

(31) Spanner, G.E., D.R. Dixon, and M.J. Fishbaugher, "Letter Report, Impact Evaluation of an Energy $avings Plan Project at Bellingham Cold Storage." Portland, OR: Bonneville Power Administration, 6/90.

(32) Spanner, G.E., and G.L. Wilfert, "Letter Report, Impact Evaluation of an Energy $avings Plan Project at Lamb-Weston." Portland, OR: Bonneville Power Administration, 6/90.

(33) Stucky, Lorna, et. al., *Impact Evaluation of the Low-Income Segment of the Weathershield and Attic Attack Program.* Augusta, ME: Central Maine Power, 6/90.

(34) Ternes, Mark, and Therese Stovall, "The Effect of House Indoor Temperature on Measured and Predicted Savings," *Proceedings of the 1988 ACEEE Summer Study on Energy Efficiency in Buildings, Volume 9, Program Evaluation.* Washington, DC: American Council for an Energy-Efficient Economy, 8/88. Pp. 9.169-9.181.

(35) Train, Kenneth and Patrice Ignelzi, "The Economic Value of Energy-Saving Investments by Commercial and Industrial Firms," *Energy, The International Journal*, Vol. 12, No. 7, 1987, pp. 543-553.

(36) White, Dennis, and Marilyn Brown, Electricity Savings Among Participants Three Years After Weatherization in Bonneville's 1986 Residential Weatherization Program, ORNL/CON-305. Oak Ridge, TN: Oak Ridge National Laboratory, 9/90.