# PGE Drive Power Program Evaluation: The Accuracy of Customer-Provided Operating Hours and Motor Loading Assumptions

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Estimates of energy savings from the use of high efficiency motors are significantly influenced by assumptions concerning motor operating hours and loadings. The objective of this evaluation was to conduct field measurements of motor operating hours and loading to determine the accuracy of original program assumptions. Short-term (three to sixteen weeks) metering of motor run-time was conducted using non-intrusive Time-Of-Use (TOU) loggers. Motor loading was determined by taking instantaneous power draw measurements.

Based on TOU data from 59 motors, no statistically significant difference was found between the original program estimate of annual operating hours and the estimate based on time-of-use (TOU) metering. Motors were found to operate an average of 93 percent of the estimated hours of operation collected from the program rebate forms. This percentage goes up to 98 percent when motors with seasonal operating schedules were removed. Field measurements of motor loadings of 39 motors averaged 74 percent loaded, almost exactly the same level as the 75 percent assumed by the program. Sample attrition reduces the ability to make general inferences from the data.

Wide variation exists in the difference between customer/dealer-provided and field-measured estimates of annual operating hours. This suggests that customers have a difficult time accurately estimating annual motor run time. Likewise, significant variation existed in the level of motor loading compared to the 75 percent program assumption. The large amount of variation in loadings found for individual motors suggests that programs aimed at appropriate sizing of high-efficiency motors in commercial and industrial applications may be desirable.

## Introduction

Demand-side management (DSM) programs designed to encourage the use of high efficiency motors have been identified as an important source of potential energy savings. Such programs are often conceived and operated on assumptions concerning change in efficiency, operating hours, and average motor loading. The increases in efficiency between standard and high efficiency motors of a given size, manufacturer, and style have been well documented (Washington State Energy Office 1993). The actual operating hours and loading of the motor in the field are typically more uncertain. Both of these assumptions are significant determinants of annual energy savings and are the primary foci of this evaluation.

The objective of this evaluation was to conduct field measurement to determine the accuracy of both annual motor operating hours and loadings in PGE's Drive Power program. A description of PGE's Drive Power Program is presented first, followed by an explanation of the methodology by which field measurements were obtained. The results of the field measurements are then presented for both operating hours and motor loading. Finally, the conclusions and recommendations of this evaluation are presented.

## Description of Program

Portland General Electric (PGE), an electric utility serving approximately 600,000 customers in Northwest Oregon, provides a rebate for the purchase of high-efficiency electric motors. The Drive Power program was created in 1991 by PGE to provide an incentive for the purchase and operation of high-efficiency electric motors in commercial and industrial applications. To qualify, a motor has to meet a minimum level of efficiency set by PGE. The program is operated primarily through motor dealers and vendors. When a high-efficiency motor is sold to a PGE customer by an approved motor dealer or vendor, a PGE rebate form is completed and a rebate mailed to the customer and the dealer. The schedule of rebates for high-efficiency motors and minimum standard efficiency levels is listed in Table 1. All motors meeting the minimum efficiency levels qualify for a rebate and no minimum operating hours are specified by the program.

## Estimated Savings From Drive Power Program

Savings from the Drive Power program are estimated by comparing the efficiency of the new high-efficiency motor to a standard efficiency motor. The standard efficiency, listed in Table 1, was derived from a Bonneville Power Administration (BPA) motor database that was, in turn, used in the creation of the MotorMaster database and

**Table 1.** High-Efficiency Motor Rebate Schedule

| Motor Horse-Power | Customer Rebate | Dealer Sales Incentive | Minimum Acceptable Efficiency | | | Standard Efficiency |
|---|---|---|---|---|---|---|
| | | | 1200 rpm | 1800 rpm | 3600 rpm | |
| 3.0 | $9.00 | $9.00 | 87.0 | 87.0 | 86.0 | 81.0 |
| 5.0 | $15.00 | $15.00 | 88.0 | 88.0 | 87.0 | 83.6 |
| 7.5 | $22.50 | $22.50 | 89.0 | 89.0 | 88.0 | 85.0 |
| 10.0 | $30.00 | $30.00 | 90.2 | 91.0 | 90.2 | 87.5 |
| 15.0 | $45.00 | $45.00 | 91.0 | 92.0 | 91.0 | 88.4 |
| 20.0 | $60.00 | $60.00 | 91.7 | 93.0 | 91.7 | 89.3 |
| 25.0 | $75.00 | $75.00 | 92.4 | 93.5 | 92.0 | 90.4 |
| 30.0 | $90.00 | $90.00 | 93.0 | 93.6 | 92.4 | 90.7 |
| 40.0 | $120.00 | $120.00 | 93.6 | 94.1 | 93.0 | 91.1 |
| 50.0 | $150.00 | $150.00 | 93.6 | 94.1 | 93.0 | 91.6 |
| 60.0 | $180.00 | $150.00 | 93.9 | 94.5 | 93.6 | 92.1 |
| 75.0 | $225.00 | $150.00 | 94.5 | 95.0 | 94.1 | 92.6 |
| 100.0 | $300.00 | $150.00 | 94.5 | 95.0 | 94.5 | 92.8 |
| 125.0 | $375.00 | $150.00 | 94.5 | 95.4 | 94.5 | 93.1 |
| 150.0 | $450.00 | $150.00 | 95.0 | 95.4 | 94.5 | 93.6 |
| 200.0 | $600.00 | $150.00 | 95.0 | 95.4 | 95.0 | 93.8 |
| Over 200[(a)] | Over 600 | $150.00 | 95.0 | 95.4 | 95.0 | |

(a) Motors in excess of 200 horsepower must demonstrate cost-effectiveness using the formula specified on the rebate form.

software compiled by the Washington State Energy Office. The MotorMaster database is also used to estimate the cost of the standard efficiency model. Hours of operation are estimated by the customer at the time the motor is sold. Motor loading is assumed to be 75 percent. The variables and assumptions used to calculate savings are described in the formula and in Table 2.

$$KWH = [(100 / EFF_S) - (100 / EFF_H)] * HP * 0.746 * LOAD * HOURS$$

## Field Measurement Methodology

To meet the objectives of this project, a monitoring scheme was employed which determines energy usage by measuring the run time and instantaneous power draw of installed motors. The steps used are summarized in Figure 1.

All PGE customers who had participated in the rebate program for efficient motors were contacted by PGE sales representatives to ascertain their willingness to take part in the monitoring phase of this evaluation. All customers who agreed to monitoring were included in the field study. There were a total of 304 motors sold through the program during the study period, from the beginning of the program in early 1991 through March 15, 1993.

Of the 304 motors that were distributed through the program, 144 were not included in the study because the customers that owned the motors were already participating in other PGE sponsored energy efficiency research. Of the remaining 160 motors, 146 (92%) agreed to participate in the evaluation by allowing PGE to conduct short-term metering of motor operations. Field monitoring was conducted from the fall of 1992 through the summer of 1993 by rotating the logging equipment between customer sites.

Program data for these 146 motors were given to field technicians to assist in the identification of program motors (e.g., horsepower, manufacturer, serial number, etc.). A short survey to collect customer characteristics and program perception data was administered during the first site visit. TOU loggers were also installed and one-time motor power draw measurements were taken at this time. TOU loggers record motor start and stop times by sensing the magnetic field generated when the motor is operating. This information can then be used to calculate total operating hours as well as hourly operating profiles for estimating peak impacts.[1] A three-phase wattmeter was used to collect instantaneous power draw measurements to determine motor loading. Power measurements were made with the assistance of a licensed electrician. Because of the added cost of obtaining the motor loading data, power draw measurements were made only on the first 44 motors for which field measurements were taken.

The second visit to each site was performed at least three weeks after the first visit. During this visit, the TOU logger was retrieved, and the logger data was downloaded to a portable computer. Also, a final survey question was asked regarding any abnormalities in the operating schedule during the monitoring period which might affect the

**Table 2.** Variables and Sources for Motor Energy Savings

| Variable | Description | Source |
|---|---|---|
| KWH | Estimated annual kWh savings. | Calculated. |
| $EFF_H$ | Efficiency rating of new high-efficiency motor. | Dealer form. |
| $EFF_S$ | Efficiency of standard replacement motor. | WSEO MotorMaster database (see Table 1). |
| HP | Horsepower. Multiplied by 0.746 for kWh. | Dealer form. Same HP for high and standard efficiency motors. |
| LOAD | Average motor loading when operating. | Assumed constant at 0.75. |
| HOURS | Annual operating hours. | Dealer form. |

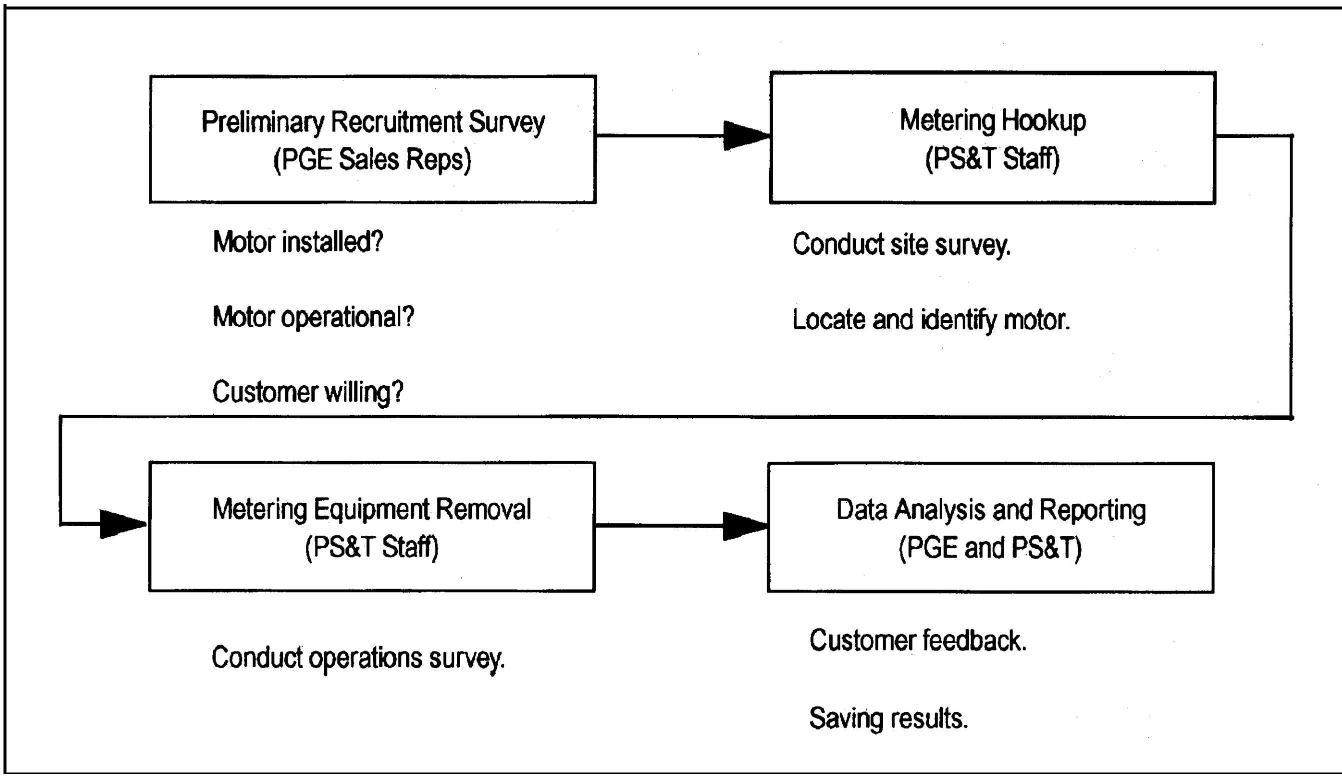


**Figure 1.** Procedural Flow for Conducting Field Measurements on Motor Operations

motor operating schedule. Results of the field monitoring were communicated to customers using a double-sided, single-sheet report for each motor. The report included motor characteristics, the calculated annual savings and simple payback, and contained a graph depicting the motor's operating schedule.

## Motor Sample Attrition

Of the 146 motors that were to be included in the field metering, only 92 were actually metered due primarily to the inability to schedule a site visit or locate the motor. Due to a variety of reasons, which are discussed in this section, the metered data was either unavailable or unusable for 33 motors leaving 59 motors with reliable field measurements. The effective sample attrition rate of 60% is high and warrants further discussion, Each of the reasons for attrition is listed in Table 3 and discussed below.

**Table 3.** Motor Sample Attrition

| Description | Total |
|---|---|
| Agreed To Monitoring | 146 |
| Unable To Schedule | 35 |
| Un-Installed Motors | 4 |
| Un-Locatable Motors | 15 |
| Metered Motors | 92 |
| Lost Loggers | 3 |
| Unreadable Loggers | 2 |
| Logger Reset | 4 |
| Non-Program Motors | 11 |
| Un-Started New Facilities | 13 |
| Reliable Hours Data | 59 |
| Reliable Loading Data | 39 |

***Unable to Schedule.*** Each of the 45 customers who owned the 146 motors had been contacted by a PGE sales representative and had agreed to field monitoring of their motors. The customers were told that a field technician from the contractor hired to conduct the field monitoring would be in contact with them to schedule the first site visit. Even so, the contractor was unable to schedule site visits in some cases. Of the 45 customers involved in the field study, 36 customers participated in the monitoring, while 9 customers, accounting for 35 motors, could not be scheduled.

***Un-installed and Un-Locatable Motors.*** A small number of motors, four, were found to be in inventory at the site visit. Occasionally, 'locating the motors to be monitored was problematic. Many of the installations were one to two years old, and the location of the motors was not tracked by the customer. Three customers (15 motors) were unable to locate the motors to be monitored.

***Lost, Unreadable, and Reset Loggers.*** In nine cases, the monitored data was unavailable due to either lost, unreadable, or reset loggers. Lost in this project means that the logger could not be located during the second site visit. Loggers on motors in hostile environments (i.e., dirty, wet, vibration, etc.) were placed in zip-lock bags for protection. Despite these precautions, the data from two such loggers were not retrievable. Each of the loggers used in this project is equipped with a small reset button located on the back of the logger. While seven motor loggers were reset between installation and retrieval, data was sufficient for estimating annual hours in three of the loggers. The data from four loggers that had been reset during the monitoring period could not be used.

***Non-Program Motors and Motors in Un-Started New Facilities.*** Eleven of the motors monitored by the field technicians were found to not be program motors. It was necessary to remove these motors from the study since their inclusion would not allow accurate comparisons to expected operating hours. Prior to comparing field monitoring estimates of operating hours to the original program estimate, it was also necessary to remove 13 motors that were installed in two new water treatment plants that had not started production. The post-metering survey at these sites revealed that plant operating time was near zero due to the fact that they had not yet been brought on line.

### Characteristics of Motors with Reliable Data

The 59 motors with reliable metering data are described by size and business type in Table 4.

Most of these motors (83%) were operating in manufacturing facilities. Over half of the motors in Table 4 are in the "Medium" size category, between 15 and 50 horsepower. The distribution of metered motors by horsepower is similar to the total program distribution, shown in the last row of Table 4. The sample of metered motors includes a greater percentage of large horsepower and lower percentage of medium horsepower than was sold through the program.

## Findings: Annual Operating Hours

Annual operating hours were estimated by multiplying the ratio of operating to metered hours by the total hours in a year (8,760). A motor that ran 360 hours over a 1008 hour metering period, for example, was estimated to operate 3,129 hours a year (360/1008 * 8,760). Loggers were left on the motors for an average of about 1600 hours (9.5 weeks). Average annual operating hours for the 59 motors identified as having reliable metered data was estimated at 5,803 hours. This compares to an average program estimate of 6,247 hours. In other words, motors were found to operate an average of 93 percent of the original program estimate of annual hours. The original program estimate and the meter based estimate of annual operating hours are plotted for each of the 59 motors in Figure 2.

To understand whether or not the program estimate of operating hours is statistically different from the metered estimate, a T-test from a paired comparison of the two estimates was calculated. The test was conducted on the difference between the program and metered estimate of annual operating hours. This type of paired comparison is only valid when the series in question is distributed normally. The test for a normal distribution of the difference indicated no statistical reason to reject the assumption of normality.[2] The issue of biased results due to seasonality reflected in the estimate of metered annual hours was also raised during the analysis. The 59 motors that were identified as having reliable metered results means that the motor was operational and that the data retrieved from the loggers is reliable. It does not mean that the metered estimate is an unbiased estimate of actual annual operating hours. Because of the short-term nature of the metering, in cases where significant seasonal patterns in operations are thought to be present, the metered estimates are clearly potentially biased.

For example, during the on-site survey, it was discovered that one of the metered motors served an air-conditioning system. When asked about any seasonal operating patterns, the customer reported that the unit runs continuously during the summer and cycles on and off during the winter, depending on the temperature. Monitoring on this motor began on October 2, 1992, and was completed January 20, 1993. Because the motor was monitored during the fall and winter, it cycled on so infrequently that the extrapolation of actual on-time produced an estimate of annual operating hours of only 86 hours. This compares to a significantly higher program estimate of 2,080 hours.

Given the short-term nature of the metering, when seasonality is present there is really no good way of estimating

**Table 4.** Comparison Motors by Horsepower (HP) and Business Type

| Sector | Small (<15 HP) | Medium (15-50 HP) | Large (>50 HP) | Total |
|---|---|---|---|---|
| Agricultural | 1 | 2 | 0 | 3 |
| Forest Products | 3 | 6 | 5 | 14 |
| Metals | 3 | 6 | 1 | 10 |
| Hi-Tech | 0 | 6 | 5 | 11 |
| Other Manufacturing | 1 | 5 | 5 | 11 |
| Commercial | 0 | 8 | 2 | 10 |
| Total | 8 (14%) | 33 (56%) | 18 (31%) | 59 |
| Total Program | 15% | 69% | 16% | 100% |

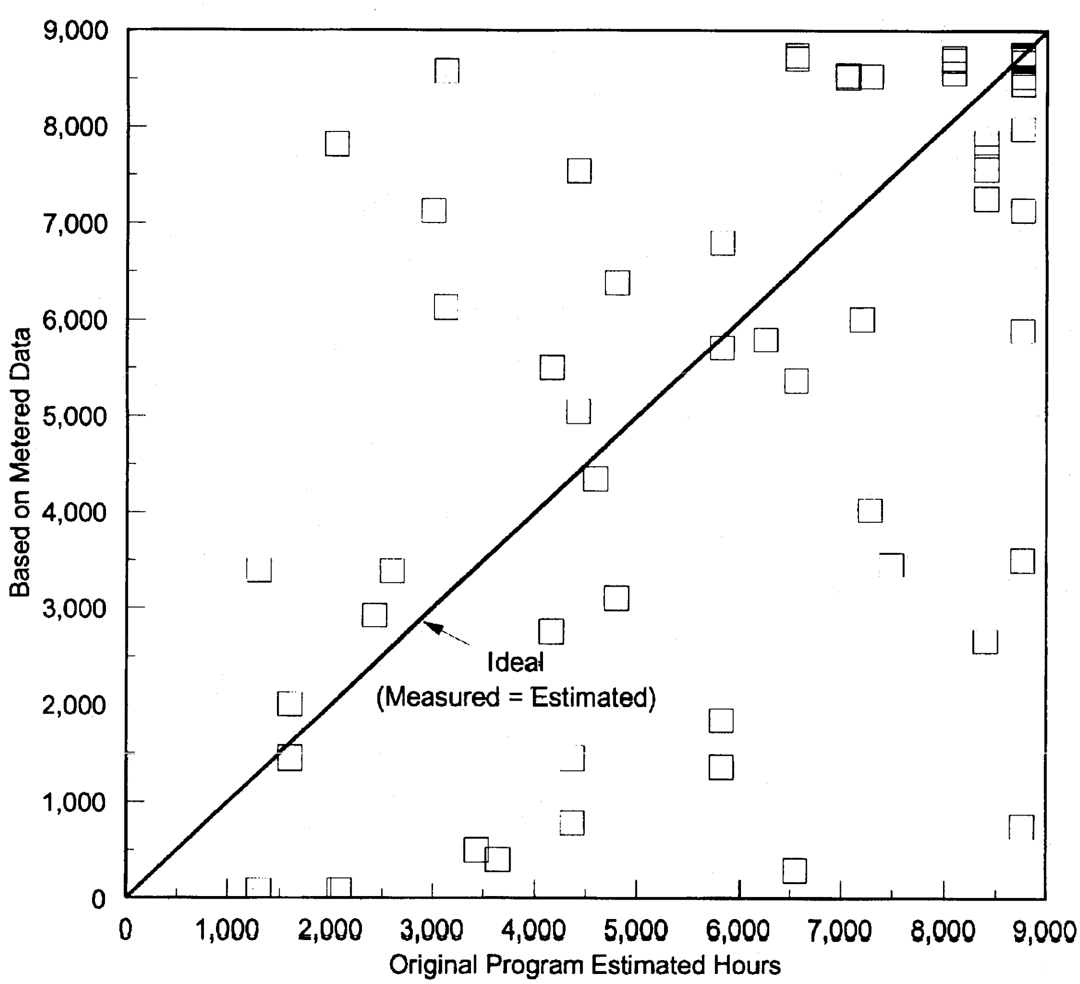


**Figure 2.** Comparison of Annual Hours of Operation

from the information in this study what the actual hours are likely to be. Including motors with seasonal operating patterns in the comparison of program to metered estimates may bias the results because the TOU meters were in place for only a small portion of a year. For this reason, motors for which the customer reported seasonal operating patterns were dropped from the comparison of program and metered operating hours. Motors of this type were identified out of the 59. Information about these eight motors is shown in Table 5, including the program- and meter-based estimates of annual operating hours.

The program estimate exceeded the metered estimate in all but one of the eight. In all cases, the percentage difference exceeded 30 percent. Statistics summarizing the operating hours for all 59 motors and for the 51 without customer-identified seasonality, referred to hereafter as the "non-seasonal" motors, are shown in Table 6.

The estimated difference between program and metered estimates of annual operating hours is reduced significantly when the seasonal motors are dropped from the calculations. When only non-seasonal motors are included in the analysis, program estimates are only 2 percent higher than meter based estimate. As mentioned above, a paired T-test to compare program and meter-based estimates of operating hours was conducted to determine whether the observed differences are statistically significant. The null hypothesis in this test is that the two estimates of annual operating hours are the same. Results of this paired comparison of means are presented in Table 7 for all 59 motors and for the non-seasonal motors.

**Table 6.** Comparison of Estimates: Annual Operating Hours

| | All Motors | Nonseasonal Motors |
|---|---|---|
| Number | 59 | 51 |
| Estimated Hours: | | |
| Program | 6,247 | 6,478 |
| Meter-Based | 5,803 | 6,344 |
| Difference | 444 | 134 |
| Ratio of Metered to Program | 93% | 98% |

The results presented in Table 7 indicate that the mean difference of 444 hours obtained from all 59 motors is not significant at the 90 percent level of confidence. Stated differently, the results indicate that the two estimates of annual operating hours are not significantly different when all 59 motors are used in the comparison. This conclusion is even stronger when the analysis is conducted on the 51 non-seasonal motors. For these motors, the results indicate that there is better than a 70 percent chance that the two estimates are the same.

**Table 5.** Motors With Customer-Implied Seasonality

| Motor ID# | Estimated Annual Hours Program | Estimated Annual Hours Meter Based | Motor Serving | Customer Provided Comments on Seasonality |
|---|---|---|---|---|
| 1 | 4,368 | 785 | Blower, car wash | Slower in winter |
| 2 | 4,368 | 1,452 | Blower, car wash | Slower in winter |
| 17 | 3,640 | 405 | HVAC | Usage increases as weather warms |
| 22 | 2,080 | 86 | HVAC (AC) | Depends on temperature, continuous in summer, cycles in winter |
| 51 | 4,160 | 5,509 | Compressor | Lower power draw in summer, business slightly lower in winter, customer investigating variance but at a loss to explain |
| 52 | 7,280 | 4,028 | Fan | Roofing demand higher in summer |
| 53 | 7,488 | 3,458 | Fan | Roofing demand higher in summer |
| 78 | 4,800 | 3,103 | Fan | Slower in winter |

**Table 7.** Analysis of the Difference Between Program and Meter-Based Estimates of Operating Hours

| Sample | N | Mean Difference | Standard Error | T-Stat | % Prob > \| T \| |
|---|---|---|---|---|---|
| All 59 Motors | 59 | 444 | 359 | 1.2 | 22.1% |
| Only Nonseasonal Motors | 51 | 134 | 388 | 0.3 | 73.1% |

To summarize, this evaluation found no significant difference between program-based and meter-based estimates of annual operating hours. This finding is even stronger when the impact of motors with seasonal operating schedules is removed from the analysis. This serves to emphasize the need for the collection and careful review of customer and site characteristics data associated with short-term metering studies. In some cases, it may be necessary to monitor a full year to adequately capture the full range of motor operations.

## Analysis by Motor Size

An assessment of the nature of the difference in estimated operating hours by motor size was also conducted. The results of this investigation are based on the 51 non-seasonal motors and are presented in Table 8.

None of the mean differences are statistically significant at the 90 percent confidence level, although small sample sizes, especially for small and large motors, make it difficult to interpret the results. The largest class in terms of numbers, medium horsepower motors, differed by only 57 hours. For this size range, the average metered estimate exceeded the program estimate.

## Motor Loading

Motor loadings were calculated by dividing the instantaneous load on the motor, expressed in horsepower, by the rated horsepower. Loads were read over approximately a five minute interval for each motor with a three phase wattmeter. Motor loading measurements were attempted for the first 44 motors metered. Five of these motors were either not operating during the site visit or the metered data was not interpretable due to nonsensical readings. In all, 39 measurements were considered valid and used for analysis. Motor loading figures range from 19 percent to 127 percent of the nameplate rating. On average, the 39 motors were operating at 74 percent of rated horsepower with a standard deviation of 24 percent. These data are plotted by horsepower in Figure 3.

The program assumption of 75 percent motor loading is very close to the measured mean. There does not appear to be any significant correlation between motor loading and size of motor based on the data plotted in Figure 3.

## Discussion

No significant difference was found in this study between customer provided estimates of motor operating hours at the time of purchase and estimates based on short-term TOU metering of actual motor operations. Although the two estimates are close on average, there is considerable variance between the two for individual motors. This would suggest that customers may not be able to accurately estimate operating hours for individual motors but there does not appear to be systematic bias in their estimates.

The motor loading data also suggest that, although there is considerable variation around the program assumption of 75% loaded, there does not appear to be systematic bias between the program assumption and metered results. The large variability in operating loads suggests the possibility of improving energy efficiency and motor operational life through better sizing of motors. Given both the small number of motors for which loads were metered (39) and the problems associated with spot metering of motor operating loads, care should be exercised in the interpretation of the data.

The use of TOU meters proved to be an effective way of obtaining actual motor operating information on which estimates of annual operating hours could be based. The use of TOU meters has the potential of significantly improving the estimates of individual motors. Since no significant difference between the meter based and original

**Table 8.** Analysis of the Difference Between Program and Meter-Based Estimates of Operating Hours by Motor Size

| Motor Size | N | Mean Difference | Standard Error | T-Stat | % Prob > \| T \| |
|---|---|---|---|---|---|
| Small Motors (<15 hp) | 7 | 351 | 576 | 0.6 | 56.5% |
| Medium Motors (15-50 hp) | 29 | (57) | 590 | (0.10) | 92.4% |
| Large Motors (>50 hp) | 15 | 402 | 640 | 0.6 | 54.0% |

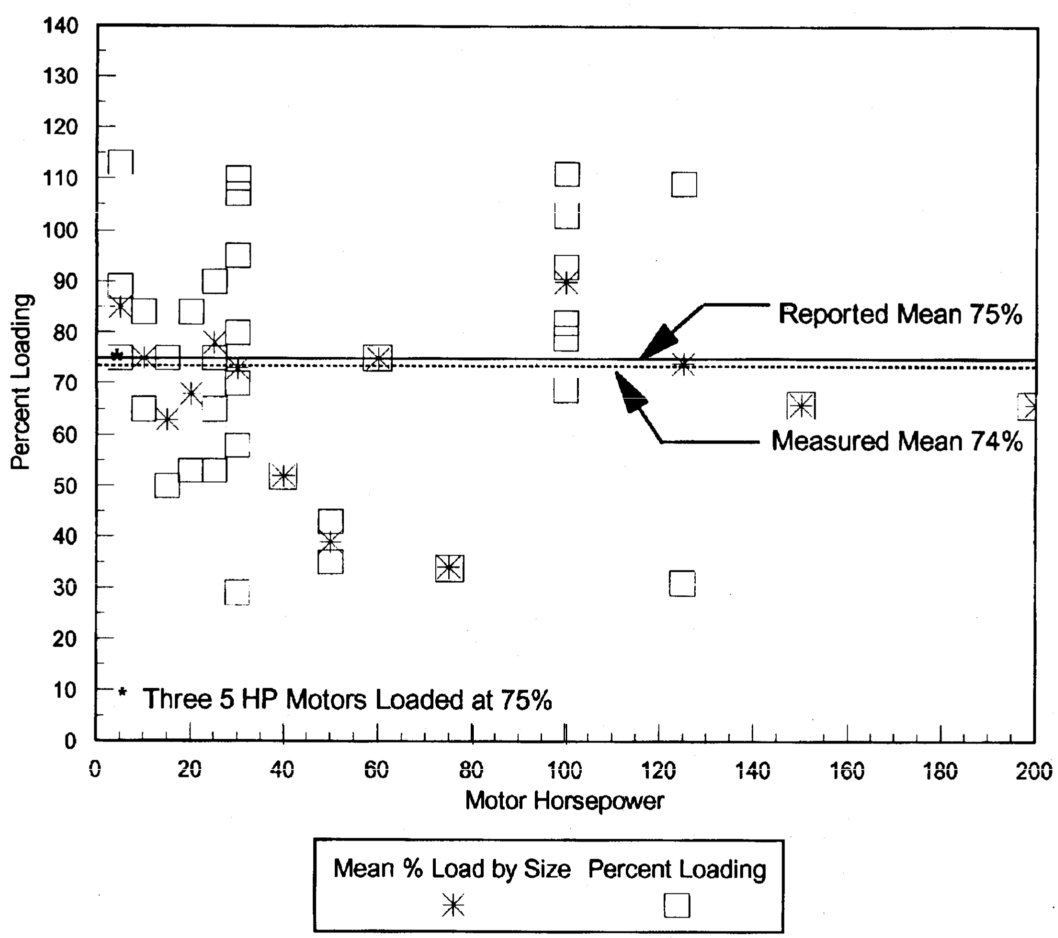


**Figure 3.** Motor Loading vs Horsepower (Mean Measure Loading 74%)

program operating hours were found on average, improving the initial estimates for individual motors may be more of a customer than a utility issue.

Sample attrition was a significant issue in this project, resulting in the loss of 60% of the motors that were planned to be metered. The field metering was well planned and coordinated with cooperation between PGE's field sales representatives, PGE's evaluation group, and the contracted field technicians. In retrospect, little could probably be done to reduce attrition levels because the primary sources of attrition are beyond the control of those conducting the study. However, the attrition experienced reduces the ability to make general inferences from the data due to the possible introduction of bias from sample attrition.

## Acknowledgments

This work was completed when the primary author was an employee of PGE. The authors wish to express their gratitude for the cooperation and assistance received from PGE staff during the completion of this project, especially Gary Margason, Cherie Merwin, and Larry Hoyez.

## Endnotes

1. More expensive TOU loggers were used in this study even though the primary objective, total operating hours, could have been achieved using less expensive run-time meters. It was felt that the additional cost for TOU capability was warranted given the potential value of the hourly use profiles for estimating peak, although the data has not yet been used for that purpose.

2. The test for normality was also conducted on the percentage difference, defined as (PROGRAM-METERED) /PROGRAM estimates. The hypothesis of normality had to be rejected in this case due to the skewed distribution of the percentage difference.

## Reference

Washington State Energy Office. *1993. MotorMaster: Electric Motor Selection Software, Version 2.* Olympia, WA.