

Cost Effective Measurement and Verification at Fairchild AFB

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Energy Retrofit Descriptions

Fairchild Air Force Base supports the USAF tanker fleet of KC-135s. The base has 79 buildings that obtain heat from the CHP. Minimal air conditioning is required in the summer because of the state of Washington's high desert environment. A base-wide EMCS (Energy Management and Control System) also allows the operations personnel to monitor the condition of each of the buildings. The base currently has 13,600 monitored points through the facilities.

The USAF has numerous projects underway focused on achieving their goal of a 35% energy use reduction by the year 2010, per the requirements of Executive Order 13123. An ESPC (Energy Saving Performance Contract) project at Fairchild Air Force Base will use the savings obtained from energy savings to pay for the HVAC infrastructure improvements. These improvements involve lighting retrofits and a replacement of the central heating plant with distributed gas boilers. This project guarantees to supply \$1.53 million in annual savings to finance these retrofits.

The lighting retrofit is relatively straightforward. The existing T-12 lights will be replaced with T-8 lighting using electronic ballasts. Incandescent lighting will be replaced with compact florescent. Incandescent exit signs will be upgraded to Light Emitting Diode (LED) exit signs.

The Central Heating Plant (CHP) supplies steam for 79 buildings. This steam plant facility will be decommissioned and smaller low pressure steam and hot water boilers will be installed to handle the space heating and other heat related loads in each of the 79 buildings, having a total square footage of 3,248,660 square feet. Energy use with the current system approaches about 178,000 BTU / square foot. Installing high efficiency boilers in each building and eliminating the base-wide steam distribution system provides energy savings.

The Central Heating Plant (CHP) operations personnel at Fairchild AFB record daily data for plant. Data was obtained from January 1, 1997 through December 31, 2000. These four years of data was used to analyze the energy use and then to construct a baseline energy use model.

CHP Analysis Approach

The data shown in Figure 1 comprises the daily data taken at the Fairchild AFB Central Heating Plant (CHP) for the baseline year 2000. The distinctive difference in summer and winter consumption is quite visible. The results of the two parameter model, shown in Figure 1, are very close to other approaches. The natural gas consumption has units of 1000 cuft and the outside air temperature axis has units of °F. Model analysis was run using ASHRAE 1050 methods, including 2 parameter, 3 parameter and 4 parameter models (Reddy 2000, Kissock, 2001). As can be seen in Figure 1, it would appear that separating the summer data from the winter data would result in a better fit. This was not the case when 3 parameter and 4 parameter models were run and the results compared. The two parameter model was used because of the reasonable fit and the simplicity of this approach over the more complex 3 and 4 parameter models.

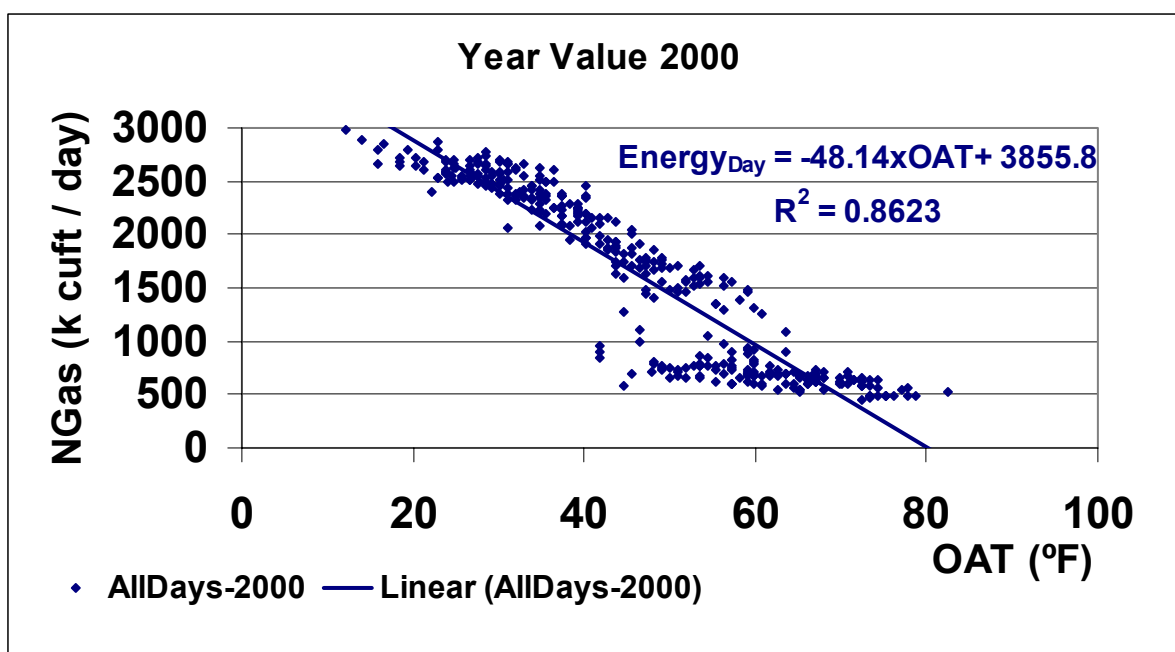


Figure 1. Baseline Data from Year 2000.

Since this contract will extend for 18 years, neither the Air Force nor the ESCO could assure that the use of the facilities would be similar over this period. Air Force Base missions can change affecting the number of people and the use of the facilities. To be equitable to all parties and still insure that the requisite savings would be obtained, a two-step approach to determining the savings for each year over the term of this contract was implemented.

M&V Overview

The first step, consumption analysis, involved determining the weather normalized baseline the energy supplied to the CHP from the CHP natural gas daily log data and then performing a weather normalized regression analysis of the natural gas monthly consumption of the new

equipment over the first full year of operation. The inherent assumption is that the use of the facilities will not change over this relatively short period of about 3 to 4 years. This is an assumption that the Air Force and the ESCO agreed were acceptable after specific adjustment factors were put in the contract to protect both parties if changes in use occurred.

The second step, efficiency analysis, involved measuring the efficiency of all of the new equipment at installation time and sampling the efficiency at the end of the first full year of operation to establish a new “BTU weighted efficiency” baseline. The BTU weighted efficiency will then be measured yearly on a sampled basis for the duration of the contract to determine the savings obtained. This process allows Fairchild AFB and the ESCO to focus on keeping the equipment performing as planned and not have to try to negotiate baseline adjustments when changes in use occur.

Baseline

Fairchild AFB collected gas use and steam use on a daily basis since 1997. The baseline involves a 2-parameter weather normalized pre-ECM energy-in compared to the post-ECM energy-in values. This is equivalent to the International Performance Measurement and Verification Protocol (IPMVP), Option C – Whole Building Approach, applied to multiple building facilities. Figure 2 shows the central heating plant with the associated measurements and losses. The advantage of using Option C is the relative simplicity and low cost of obtaining the measurements. By knowing the heat input (natural gas) to the CHP and the local weather, a weather-normalized baseline for energy-in can be built.

Another beneficial aspect of using Option C is that losses do not have to be estimated. The IPMVP Option C’s methods account for these losses in the energy-in measurements. Estimating losses from steam / boiler systems with lengthy distribution lines is problematic at best. Significant errors will likely occur, since the steam lines are several miles in length and of an unknown condition. If this is required, the plant losses (plant efficiency) can be determined from the difference in the energy content of the natural gas and the energy content of the steam output. The distribution system losses can be estimated using the size of the pipe, the insulation and assuming no leaks. Usually, the size and length of the pipe can be estimated. Unfortunately, the insulation has usually degraded to an unknown level and leaks will exist in the pipe and the steam traps associated with the main feed line will have an undetermined leak rate. Finally, the condensate return from the steam traps on the heating or process equipment in the facilities is typically not measured. In summary, all of these losses cannot be determined to a reasonable level ($\pm 5\%$ or so) without a significant increase in measurement and cost. By using Option C to compare energy-in for the baseline case and energy-in with the Post-ECM case, these measurement and cost issues are avoided.

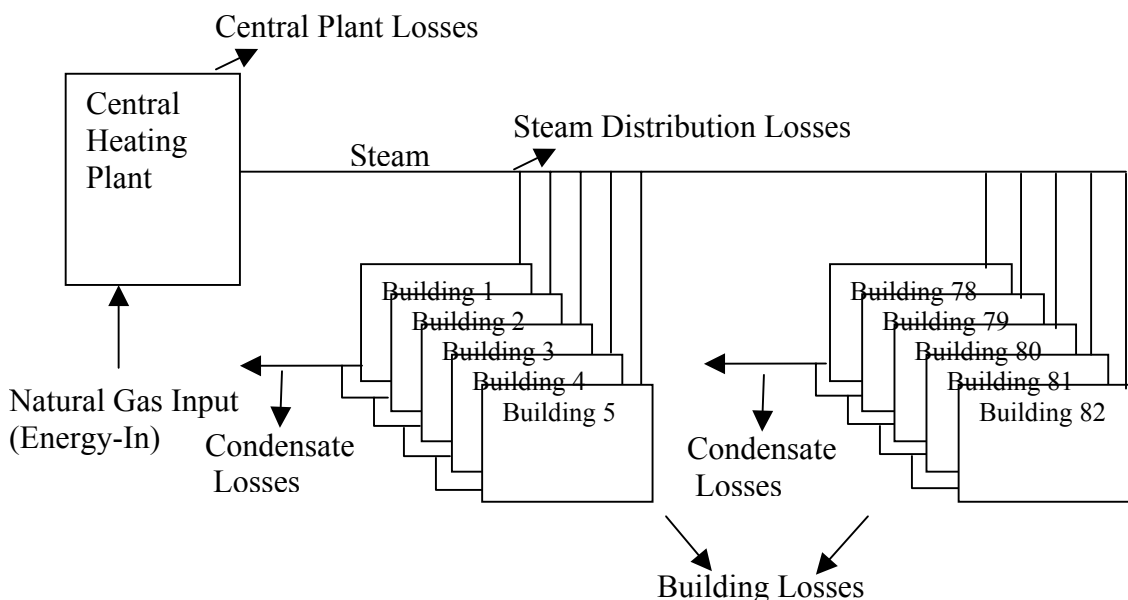


Figure 2. Baseline Configuration (Pre-ECP)

In Table 1, the Raw Data column represents the data as received. The Actual Data had data fills in the missing data for each year by taking the raw data consumption, performing a regression to obtain a model for gas consumption and then filling in the missing data using those regression coefficients. The uncorrected data results in errors as high as 17% with a three year average error, from 1997 to 1999, of 9.1%. The corrected, filled in, data results in errors up to 11.8% with the three year average error at 7.4%.

	Raw	Actual
1997	546,215	546,215
1998	490,531	523,565
1999	566,402	578,576
2000	588,151	593,635
1997	7.13%	7.99%
1998	16.60%	11.80%
1999	3.70%	2.54%
3yr Avg	9.14%	7.44%

Table 1. Non-normalized Data Errors

Analyzing the data for each year showed that the weather normalized consumption for each of the 4 years of data maintained a constant level (within about $\pm 5\%$). Picking the year 2000 weather and summing consumption for each year showed that the end result was within $\pm 5\%$ of any other year. The Raw data column is the data as received. In the 2-P, 2P-W/S, 3-P and 4-P columns, the data shown is the total consumption calculated for the year using the regression model parameters from the Year 2000 analysis. The 2-P is a two parameter regression analysis. The 2P-W/S uses the winter and summer data separately and sums the total consumption for the year. The 3-P and 4-P columns are three and four parameter

regressions respectively. The Raw data column illustrates the impact of not performing a weather normalization as errors as high as 17% were observed. The total corrected consumption for the year 2000 came to 593,635 in units of 1000 cubic feet of natural gas. This provided high confidence that the baseline model would be valid over several years of varying weather and facility use at Fairchild AFB. The calculated consumption for the years 1997 through 2000 is shown in Table 1.

	Raw	Actual	2-P	2P -W/S	3-P	4-P
1997	546,215	546,215	570,586	582,040	570,754	571,080
1998	490,531	523,565	536,267	563,682	548,010	545,287
1999	566,402	578,576	553,576	564,948	553,324	553,848
2000	588,151	593,635	593,635	594,257	593,635	593,635
1997	7.13%	7.99%	-4.46%	-6.56%	-4.49%	-4.55%
1998	16.60%	11.80%	-2.43%	-7.66%	-4.67%	-4.15%
1999	3.70%	2.54%	4.32%	2.36%	4.36%	4.45%
2000	0.00%	0.00%	0.00%	0.10%	0.00%	0.00%

Table 1. Calculated Consumption Based on Year 2000

It should also be noted that the actual consumption varied considerably from 1997 to 2000. Had the simple “compare the utility bill” method been used errors as high as 17% could occur. Data filling reduced these errors to under 12% and weather normalizing this data reduced these errors to under 5%, with the exception of separating the Summer / Winter data. Table 1 illustrates that year to year changes in temperature have a much smaller impact on the errors in the energy use calculations if the consumption data is weather normalized. The climate at Fairchild AFB is high desert, meaning that humidity is not an issue. This weather normalization used outside temperature only.

The next concern that needed evaluation was the impact to calculation accuracy due to using average monthly temperatures with the Year 2000 monthly model parameters instead of taking average daily temperatures with the Year 2000 daily model parameters. The contractor planned to manually read each of the gas meters installed in each of the 79 buildings for the first full year of operation. This was more cost effective than installing totalizers on the gas meters, connecting these to the EMCS and setting up the trend logs. A monthly model was constructed from the daily data using Year 2000 data. Missing data was filled in using the daily model so that the monthly model had complete consumption for each month. Two models (equations) were generated – a Year 2000 Daily Model and a Year 2000 Monthly Model. These models were then applied to the average daily and average monthly temperatures for each of the years shown in Table 2. The only year that was over 1% error was 1998, the year which required significant data filling. Other than 1998, the daily and monthly data was within $\pm 1\%$. This analysis assumes that the reading dates include full month data.

In 2000, the equation are:

$$\text{Energy}_{\text{DailyCalc}} = -48.1401 \times \langle \text{OAT} \rangle_{\text{Daily}} + 3855.7721 \quad \text{Eqn 1}$$

$$\text{Energy}_{\text{MonthlyCalc}} = -53.6075 \times \langle \text{OAT} \rangle_{\text{Monthly}} + 4109.6108 \quad \text{Eqn 2}$$

Year	Data Filled Consumption (1000 cuft)	Daily Calculated Consumption (1000 cuft)	Monthly Calculated Consumption (1000 cuft)	Calculated Change (%)
1997	546,215	570,586	568,202	0.4%
1998	523,565	536,267	529,986	-1.1%
1999	578,576	553,576	549,260	0.8%
2000	593,635	593,635	593,352	0.0%

Table 2. Comparison of Daily / Monthly Consumption using Year 2000 parameters.

The data analysis in Table 2 justifies using monthly data for determining the energy use model for the first post-ECM year of operation. The meter reading expense involved subcontracting to a local utility to read the meters monthly. It is very important that the meter reading date be included with the meter consumption reading. When calculating the first year consumption model, the average daily consumption and average monthly outside temperature must be used. Otherwise the calculation will not be weather normalized, which can result in errors in the range of $\pm 15\%$, depending upon that years specific weather pattern.

The year 2000 will be used for the baseline for savings calculations. The Baseline_EnergyIn is 593,211 x 1000 cubic feet of natural gas. The year 2000 weather will be used to determine what the consumption would have been if the year 2000 weather occurred in the first full year of operation. This calculated consumption will be reconciled with the year 2000 consumption to determine savings. This savings must meet the guaranteed level for the contractor to receive full payment.

Hourly data aggregated to daily consumption still remains the preferred data at any site. With hourly data, use patterns can be monitored for changes and can be clearly defined. Daily data enables operations personnel (and the contractor) to localize degraded efficiency in specific boilers in almost real time. However, as the above analysis shows, monthly data is quite suitable for determining the energy savings at Fairchild AFB.

First Year Measurements / Savings Calculations

Next, the first year predicted savings will be validated by measuring the gas input to heat the same set of buildings. The use of each building is assumed to be the same as the baseline year. The four years of data taken from 1997 through 2000 validates this assumption, since the weather normalized error was under 5% over these four years. The contractor was allowed a $\pm 2\%$ error range and will make the savings estimate conservative to accommodate any other errors that may occur in the measurements.

Each building has individual gas meters installed. Although these meters will be read manually on a monthly basis, they are configured with a totalizer output so that the EMCS can connected to monitor consumption on a daily or even hourly basis in the future. Because of the cost involved, these were not connected to the Energy Management System. The

current plan specifies manually reading the meters during the first full year of operation to keep the cost low. Figure 3 shows the postECP configuration.

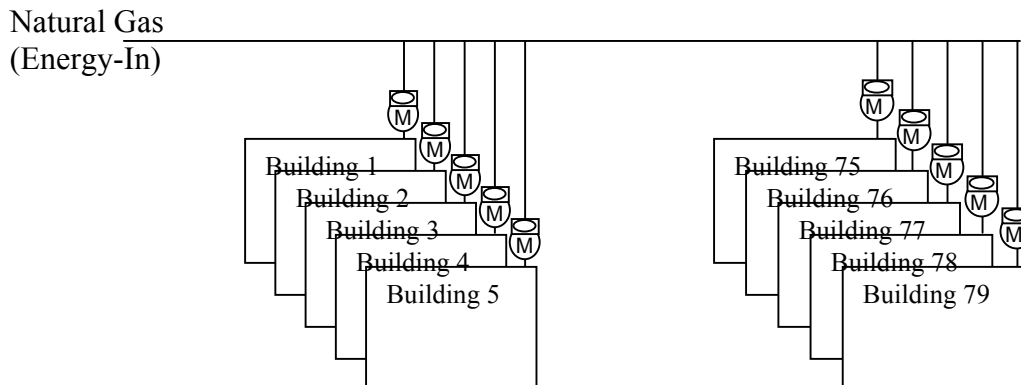


Figure 3. End of Year 1 Configuration (Post-ECP)

The cost for the consumption savings analysis process involved creating the baseline from existing CHP data, installing gas meters (which was required anyway), reading the meters (about \$300 per month for the first year to read the meters, contracted out to the local gas company) and performing the calculations. Option C is very cost effective for this stage of the project.

Once all of the monthly readings are obtained, the total year's consumption will be compared to the consumption calculated from the monthly model. The following procedure will be followed:

1. Total the natural gas consumption for the first full year of operation. This is the PostECP energy use for year 1.
2. Obtain the average monthly temperature from the weather service or by summing each day's high and low temperature and dividing by 2 x DaysOfThatMonth.
3. Calculate what the gas consumption for each month would have been in Year 1 without the ECP using the following equation with the Year 2000 parameters.

$$\text{Energy}_{\text{MonthlyCalc}} = (-53.6075 \times \langle \text{OAT} \rangle_{\text{Monthly}} + 4109.6108) \cdot \text{Days_In_Month} \quad \text{Eqn 3}$$

4. Sum the monthly total for all 12 months. CalcYear1_Energy is the modeled energy use for the first year of operation.

$$\text{CalcYear1_Energy} = \sum_{M=1}^{12} \text{Energy}_{\text{MonthlyCalc}} \quad \text{Eqn 4}$$

5. This difference between the total calculated consumption using the Year 2000 baseline weather parameters and the Year 1 Energy Consumption is the energy savings obtained.

$$\text{Year1_EnergySavings} = \text{CalcYear1_Energy} - \text{MeasuredEnergy}_{\text{Year1}} \quad \text{Eqn 5}$$

6. The Year1_EnergySavings can then be compared to the guaranteed savings. If the energy savings is greater than the guarantee, full payment is made to the contractor. If not a reduced payment is calculated based on the utility rate (with any agreed to escalation) in place when the contract was signed.

The use of these facilities will likely change over the term of the contract. Therefore, the efficiency of the installed equipment will be used to determine variations from the energy savings that were calculated above. To accomplish this, the equipment efficiency will be measured when boilers are installed. A BTU weighted efficiency will be used.

To keep the costs affordable for these measurements, all parties agreed to measure all large boilers yearly and sample 10% of the medium and small boilers yearly. Of the 109 boilers, 5 are large, 100 are medium and 4 are small.

Boiler efficiency will be measured using ASME PTC 4.1a "Steam Boiler Efficiency Measurement". The Power Test Code (PTC) 4.1 from the American Society of Mechanical Engineers can be used for steam and hot water boilers and has a simplified calculation and summary sheet for data collection. It provides two methods for measuring boiler efficiency. The first method, energy in and energy out measurements, requires the measurement of the water or steam flow, temperature difference between the supply and return and the gas consumption. Accuracy is difficult to obtain using field measurements. The second method is called the heat loss method. This method calculates the percentage of energy loss from the flue temperature, O₂, CO, radiated and other losses. The total loss is then subtracted from 100% to get the boiler efficiency. This is the preferred method on smaller boilers because of the inherent lower cost of making the measurements. As long as the same loss terms are used from year to year, the goal of detecting degrading performance due to burner inefficiencies, tube scaling or soot will be obtained.

On-going Year Measurements / Savings Calculations

PostECP savings for years two through the end of the contract will be determined by sampling the weighted efficiency of the 109 boilers. The intent is to keep the efficiency high throughout the term of this contract. Table 3 lists the boiler categories and average size for each boiler. Fifteen boilers (the 5 large boilers and 10 small / medium boilers) will be measured, which results in almost 30% of the boiler capacity, will be measured yearly.

Boiler Size	Number of Boilers	Number of Boilers Measured	Average Size (MMBTU)	Total BTU %	Total BTU % Measured
Large (> 8 MMBTU/hr)	5	5	9.6	22	22
Medium	100	10	1.7	77	7.7
Small (< 0.5 MMBTU/hr)	4		0.6	1	0.1
Total	109	15			29.8

Table 3. Boiler Summary

The method for calculating the impact of efficiency on the energy savings requires several steps as described below.

1. Measure the efficiency of the sample set of boilers.
2. Calculate the weighted efficiency from the following equation using the BoilerEff and BoilerBTU for each boiler measured:

$$\text{BoilerWeightedEff} = \frac{\sum \text{BoilerEff} * \text{BoilerBTU}}{\sum \text{BoilerBTU}} \quad \text{Eqn 6}$$

The weighted efficiency can then be used to determine the natural gas saved by comparing Year N's weighted efficiency to that of the baseyear efficiency.

3. Using the procedure below determine the net gas savings.

The heat supplied is assumed to be constant for the before and after case. The heat supplied is simply the measured efficiency times the total BTU or cubic feet of natural gas. Equation 7 and 8 show that the before and after equations are equal to the same total supplied heat and therefore, Equation 9 can be used to calculate the total energy used in Year N based on the measured efficiency.

$$\text{TotalEnergy_Year1} = \frac{\text{Year1_EnergyIn}}{\eta_{\text{Year1}}} \quad \text{Eqn 7}$$

$$\text{TotalEnergy_YearN} = \frac{\text{YearN_EnergyIn}}{\eta_{\text{YearN}}} \quad \text{Eqn 8}$$

Since the total energy is assumed to be equal for the comparison years,

$$\text{YearN_EnergyIn} = \frac{\eta_{\text{YearN}}}{\eta_{\text{Year1}}} \cdot \text{Year1_EnergyIn} \quad \text{Eqn 9}$$

In this case, the Year1_EnergyIn is equal to the measured gas consumption during the first year of full operation.

4. Any change in efficiency will result in a change in the energy use calculated after the ECP was completed. Calculate the change in energy savings due to a change in efficiency by taking the difference between Year1_EnergyIn and YearN_EnergyIn.

$$\text{YearN_EfficiencySavings} = \text{Year1_EnergyIn} - \text{YearN_EnergyIn} \quad \text{Eqn 10}$$

$$\text{YearN_EfficiencySavings} = \left(\frac{\eta_{\text{YearN}} - \eta_{\text{Year1}}}{\eta_{\text{YearN}}} \right) \cdot \text{Year1_EnergyIn} \quad \text{Eqn 11}$$

4. Subtract the YearN_Energy (Eqn 9) from Year1_EnergyIn (Eqn 5). This YearN_EfficiencySavings yields the savings difference from the first year efficiency and the Year N efficiency. Adding the consumption based savings and the efficiency based savings then provide the total YearN_EnergySavings (Eqn 12). If the YearN_Savings is higher than the guarantee, the contractor made the required savings. If not, subtracting the YearN_Savings from the guarantee will yield the loss difference.

$$\text{YearN_EnergySavings} = \text{Year1_EnergySavings} + \text{YearN_EfficiencySavings} \quad \text{Eqn 12}$$

5. The EnergyReconciliation is determined by subtracting the YearN_Savings from the GuaranteeSavings. If the EnergyReconciliation is positive, the efficiency based savings exceeded the guarantee. If the amount is negative, the savings has a shortfall.

$$\text{EnergyReconciliation} = \text{YearN_EnergySavings} - \text{GuaranteeSavings} \quad \text{Eqn 13}$$

6. The cost determination is then the EnergyReconciliation times the Year N energy price.

$$\text{CostReconciliation} = \text{EnergyReconciliation} \cdot \text{YearNEnergyPrice} \quad \text{Eqn 14}$$

Conclusions

Cost effective measurements can be implemented to determine savings from major projects. This project involved over \$25 million in upgrades and the M&V cost estimate for the entire 22-year contract period is under \$500K, or about 2% of the contract. Establishing a measurement based savings calculation will also tend to keep all parties focused on keeping the equipment operating at the specified efficiency. This benefits both the base and the contractor. The base maintains the savings and experiences lower utility costs. The contractor stays active and knowledgeable about the facility and will then have additional opportunities for additional infrastructure improvements.

In the past, stipulation was almost always the chosen method of determining savings for ESPC contracts. As the industry matures and learns how to cost effectively measure energy consumption, more savings determinations will be based on measurement. Measurement based savings determinations also build confidence in the programs being implemented. Personnel at Fairchild Air Force Base and the contractor addressed the challenges of using measurements to determine the energy savings resulting from their ESPC contract.

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