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Impact Evaluation of a Refrigeration Control System Installed at Columbia Colstor

L. E. Wrench
G. E. Spanner
L. A. Klevgard
G. P. Sullivan

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Prepared for Sheila Riewer
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Pacific Northwest Laboratory
Richland, Washington 99352

Summary

This impact evaluation of a computer-based refrigeration control system (RCS) installed at Columbia Colstor in 1990 was conducted for the Bonneville Power Administration (Bonneville) by Pacific Northwest Laboratory (PNL). Concurrent with installing the RCS, the plant was expanded by adding 13,900 m^2 (150,000 ft^2) of storage space and five freeze tunnels. Because this project involved a significant plant expansion, it was ineligible for participation in Bonneville's Energy $avings Plan Program (E$P). Therefore, a special contract was negotiated. This contract followed, to the extent possible, the E$P principles, adminstrative procedures, and acquisition payment.

The primary objectives of this impact evaluation were to assess how much electrical energy is being saved at Columbia Colstor as a result of the Bonneville's acquisition payment and to determine how much the savings cost Bonneville and the region. Another objective was to review the verification method used in the completion report and to suggest a method that could be used in the future for verifying the energy savings of other similar projects. The impact of the project was evaluated with a combination of engineering analysis, billing analysis, financial analysis, interviews, and submittal reviews (Columbia Colstor's completion report and proposal).

Based on this impact evaluation, energy savings from this project are expected to be at least 4,130,700 kilowatt-hours/year (kWh/yr), or 0.47 average megawatts (aMW). Because the refrigeration system at Columbia Colstor provides cooling to both the storage rooms and the freeze tunnels, it is not possible to state savings on a per-ton basis. The project cost $287,528 to install, and Columbia Colstor received payment of $180,375 (1991 dollars) from Bonneville for the acquisition of energy savings. The real levelized cost of these energy savings to Bonneville is 4.5 mills/kWh (in 1993 dollars) over the project's assumed 15-year life, and the real levelized cost to the region is 7.6 mills/kWh in 1993 dollars, not including transmission and distribution effects.

Because this project did not meet Columbia Colstor's criterion for funding energy conservation projects (simple payback of less than three to five years), it would not have been installed without the acquisition payment offered by Bonneville. Therefore, it is not considered to be a free rider.

Contents

Figures

Tables

1.0 Introduction

This report describes Pacific Northwest Laboratory's (PNL's)[a] evaluation of the impact of an energy conservation project installed in the fall of 1990 at Columbia Colstor in Quincy, Washington. The project at Columbia Colstor is one in a continuing series of industrial energy conservation projects to have its impact evaluated by PNL. This project involved a plant expansion in addition to the energy conservation project installed, so it did not meet the Energy $avings Plan (E$P) Program eligibility criteria. The development and administration of this project followed the E$P principles to the extent possible. Bonneville's Upper Columbia Area Office used a portion of its E$P budget to fund the acquisition payment for this project.

For the Columbia Colstor project, the one-time acquisition payment offered was 4.02¢/kilowatt-hours (kWh) saved (as estimated in the project proposal) in the first year. Because Grant County Public Utility District #2 (Grant County PUD) does not obtain all of its power from Bonneville, the E$P causes the acquisition payment to be reduced by 25% for a net of 3.02¢/kWh.

The general objective of the impact evaluation was to determine how much electrical energy is saved by the project and at what cost to Bonneville and to the region. In support of this general objective, answers were sought to the following questions:

1. How much **electrical energy is saved annually** by the energy conservation project in terms of kilowatt-hours, kilowatt-hours per unit of plant output (unit savings), and average megawatts (aMW)? Also, did any **fuel switching** result from implementing this project?

2. If the project improved the productivity of the process, did the firm then **increase output of the process** to take advantage of the productivity improvement? Did the change in output result in a net increase or decrease in energy used by the process? Did the change in output cause changes in output at the firm's other plants in the region?

3. What was the **net impact** to the serving utility in terms of electrical energy consumption (in kilowatt-hours) from implementing the project?

(a) Pacific Northwest Laboratory is operated for the U.S. Department of Energy by Battelle Memorial Institute under Contract DE-AC06-76RLO 1830.

4. What are the **real levelized costs** of the project from the perspectives of Bonneville and the region?

5. How much of the project's **impact can be attributed** to the acquisition payment from Bonneville?

1.1 Approach for Impact Evaluation

Before selecting individual energy conservation projects for impact evaluation, PNL developed a general impact evaluation methodology (Spanner et al. 1988). The major finding of the methodology development was that in the industrial sector, energy conservation projects must be evaluated on a case-by-case basis. Accordingly, the general methodology consists of a variety of impact evaluation techniques that can be applied to individual projects according to the specific circumstances.

To evaluate the impact of installing the computerized refrigeration control system (RCS) at Columbia Colstor, five techniques were selected: engineering analysis, billing analysis, financial analysis, site visit and interview, and review of Columbia Colstor's completion report and proposal. No on-site submetering was performed by PNL for this project. Instead, billing data were relied upon by PNL to determine the project's impact.

Representatives from PNL visited Columbia Colstor on March 11, 1992, to view the project first-hand and to conduct a technical and financial interview with Columbia Colstor's plant engineer, chief engineer, and controller.

1.2 Project Description

The energy conservation project at Columbia Colstor is a computer-based RCS that was installed in September 1990 for controlling the plant's refrigeration equipment. The system consists of a mini-computer and software; computer peripherals; and sensors to measure pressure, temperature, humidity, electrical current, and power at various points throughout the plant. The RCS reduces energy consumption by:

- increasing suction pressure and/or reducing discharge pressure when permissible to minimize pressure rise in the compressors and thereby reduce power consumption

- controlling the defrost cycle according to need instead of at fixed intervals

- limiting evaporator fan operation as permissible

- controlling condenser fans and pumps based on wet bulb and saturation temperatures to minimize head pressure

- sequencing compressor operation so that minimum compressor power is used to meet cooling needs at all times

- recording the equipment operating parameters so that malfunctioning equipment can be readily detected and repaired or adjusted.

This RCS was Columbia Colstor's first attempt to use an automated system for improving the energy efficiency of its refrigeration equipment. Since this system was installed at the Quincy plant in 1990, at which time it represented the state-of-the-art, many advances in refrigeration control have occurred. This RCS is now obsolete because more recent systems have more powerful micro-processors, more sophisticated software, and more elaborate sensors. Columbia Colstor has installed later generation systems at its plants in Kennewick and Woodland, Washington, and those systems have benefitted greatly from experience gained at the Quincy plant.

At about the same time that the RCS was installed, Columbia Colstor expanded its plant. An additional storage room of 13,900 m^2 (150,000 ft^2) with an insulated floor was built, bringing the total storage space to 43,700 m^2 (470,000 ft^2). Also, five freeze tunnels were added between Columbia Colstor and its adjacent customer. The tunnels, operated by Columbia Colstor, are used about five months each year to process vegetables. All of the refrigeration equipment in Columbia Colstor's plant expansion is also controlled by the RCS.

In the completion report, the energy savings for this project were verified by comparing the actual annual usage (AAU) to the original anticipated annual usage (OAAU), with both numbers normalized for the amount of food processed in the freeze tunnels and adjusted by the expected percentage savings from engineering calculations and anecdotal observations. This verification method is explained in Appendix D, which contains a copy of Exhibit C of the contract between Bonneville and Grant County PUD. In this method, if the OAAU and the AAU are equal, it shows that the anticipated savings are realized by the project. The AAU calculations from the project's completion report are included as Appendix E. In the completion report, it was concluded that savings are at least as great as expected in the proposal because the AAU is smaller than the OAAU, although it was not possible to estimate by how much the savings were greater. At some point before PNL received the completion report, the AAU was subtracted from the OAAU to estimate savings, which is inappropriate.

Columbia Colstor submitted two documents to Bonneville: a proposal and a completion report. The proposal described the project and laid out Columbia Colstor's expectations with regard to costs and benefits. Included was a calculation of the project's expected simple payback. A completion report was submitted to Bonneville after the project was installed. This document listed the actual costs of the project along with a calculation of the energy savings that had been achieved. A copy of the cover sheet from the proposal is included as Appendix B.

The total cost to Columbia Colstor for this project was $287,528. Grant County PUD paid $3,963 in administrative costs, and Bonneville paid $180,375 for the energy saved. The acquisition payment was calculated by multiplying the estimated annual energy savings in the proposal by 4.02¢/kWh, and multiplying this result by 0.75 because Grant County PUD does not obtain all of its power from Bonneville (5,982,594 kWh • 4.02¢/kWh • 0.75 = $180,375). After applying the cost share percentage, the effective acquisition payment rate is 3.02¢/kWh.

1.3 Summary of Project Impacts

This project is expected to save at least 4,130,700 kilowatt-hours annually, or 0.47 aMW. Over the assumed 15-year life of this project, the levelized cost to Bonneville is 4.5 mills/kWh (1 mill = 1/1000 of a dollar), and cost to the region is 7.6 mills/kWh. These costs are in real 1993 dollars and do not include additional savings that accrue if transmission and distribution losses are considered. The levelized cost to Bonneville including transmission and distribution losses is 4.2 mills/kWh, and the cost to the region is 7.1 mills/kWh.

Without the acquisition payment from Bonneville, this project did not meet Columbia Colstor's funding criterion for energy conservation projects; however, it did meet the criterion with the acquisition payment. Therefore, we conclude that it would not have been installed without the acquisition payment from Bonneville and is therefore not a free rider.

2.0 Impact Evaluation

The following section addresses the five major objectives of the impact evaluation as stated in the introduction.

2.1 Energy Savings and Fuel Switching

1. ***How much electrical energy is saved annually by the project in terms of kilowatt-hours, kilowatt-hours per unit of plant output, and average megawatts? Also, did any fuel switching result from implementing this project?***

Determining the energy savings for this project is difficult due to the fact that Columbia Colstor expanded their operation at roughly the same time that the refrigeration control system was installed so that no baseline data are available for comparison purposes. New and used refrigeration equipment totaling 485 kW (650 hp) was added to the existing facility. In addition, 5,965 kW (8,000 hp) of new refrigeration equipment was installed along with a 13,900 m^2 (150,000 ft^2) expansion of the storage area and five freeze tunnels for processing vegetables.

Three approaches to determining expected savings were made. The first approach could be termed the engineering calculation method. These calculations were included in the proposal for the project. The assumptions made for, and the results of, these calculations are described in the Engineering Calculations section below.

The second approach was the calculation of Actual Annual Usage (AAU). This calculation is based in part upon the percent savings estimate generated by the engineering calculation. A discussion of how this calculation was applied in the completion report, as well as a general discussion about the appropriateness of this calculation, are included in the AAU Calculation section below.

A final approach attempted to use available energy-use information (i.e., electric billing data), production information (pounds of product in storage, pounds of product processed in the freeze tunnels), and outdoor temperature data to calculate savings. These data were used to normalize for both the difference in weather conditions between the before- and after-retrofit period, as well as to attempt to disaggregate the changes in energy use because of the expansion from the change in use as a result of the installation of the retrofits. The results of these calculations are described in the Billing Data Calculations section below.

2.1.1 Engineering Calculations

In the completion report, the energy savings calculations were broken down into two sections: one dealing with the existing control room and one dealing with the new engine room (see Table 2.1). Five areas were identified in the existing control room where energy savings would be realized: fan control, defrost control, optimum compressor sequencing, suction pressure control, and discharge pressure control. The two areas identified in the new engine room having energy savings were compressor sequencing and control and head pressure control.

Existing Control Room Savings

Energy savings in each of the above-mentioned areas were calculated from assumptions based on information from past experience. The fan control savings were estimated to be 507,730 kWh/yr (based on 414 kW of load [evaporator and circulating fans, along with compressors used to remove excess heat] utilized 70% of the time, 8760 hours/year with a 20% reduction due to the computer control system).

The defrost control savings were estimated to be 419,780 kWh/year. Columbia Colstor and Pacific Micro-Control (vendor of the computer control system) determined that 20 minutes/day of excess defrost time was a conservative estimate of savings realized by the computer-controlled system. Therefore, the 1,380 kW (1,850-hp) compressors operating 50 minutes less per day (20 minutes of reduced excess defrost times 2.5 minutes of reduced compressor time per minute of reduced excess defrost) results in savings of 419,780 kWh/year.

Table 2.1. Energy Savings from Engineering Calculations

	Existing Engine Room (kWh/yr)	New Engine Room (kWh/yr)	Total (kWh/yr)
Fan Control	507,730	--	507,730
Defrost Control	419,780	--	419,780
Compressor Usage	1,605,811	3,449,273	5,055,084
Totals	2,533,321	3,449,273	5,982,594

The other measures, optimum compressor sequencing, suction pressure control, and discharge pressure control were estimated with a compressor usage factor. This factor was determined by noting that the compressors run roughly 70% of the time. This figure was reduced to 60% to ensure conservative estimates. Then, the reduction (in hours/year) from the first two items (fan control and defrost control) was calculated. They were 91 and 304 hours/year, respectively. Subtracting these hours from the 60% annual run time yields a 0.55 compressor utilization factor. The optimum compressor sequencing savings percentage was estimated to be 15% (based on past projects that have a typical range of 10-25% savings). The suction pressure control will result in a 3% energy reduction. The total pressure differential is 228 kPa (33 psi). Again, based on past applications, computer-controlled systems have raised the suction pressure from 6.9 - 20.7 kPa (1-3 psi). This project assumed a 6.9 kPa (1 psi) increase, resulting in the 3% savings mentioned. The discharge pressure control measure was assumed to contribute an 8% reduction in energy (typical projects using this measure realize savings of between 5 and 10%). This is accomplished at night when the ambient temperature is lower, thus allowing the condenser to reduce the discharge temperature by leaving the fan and spray pump running. Since the fan and spray pump's energy usage is negligible compared to the compressors', it is beneficial (resulting in energy savings) to allow the condenser to reduce the compressor discharge pressure. Combining the 15% savings from compressor sequencing, 3% savings from suction pressure control, 8% savings from discharge pressure control and taking into account the interactive effects of these measures, a resultant savings of 24.15% (1-(0.85)(0.97)(0.92) = 24.15%) was determined to be realistic. Therefore, given the 1,380 kW (1,850-hp) compressor load, the 0.55 usage factor and 24.15% savings, the annual savings would be 1,605,811 kWh/year. The total savings for the existing engine room would therefore be 2,533,321 kWh/year (507,730 kWh/yr fan control savings + 419,780 kWh/yr defrost control + 1,605,811 kWh/yr optimum compressor sequencing, suction pressure control, and discharge pressure control).

New Engine Room Savings

Savings in the new engine room will be realized from two main measures: compressor sequencing and control and head pressure control. The computer-controlled system will allow the operator to optimize the schedule of the compressors to match the production load. Columbia Colstor assumed a 10% savings (similar applications have achieved 10-15% savings). Likewise, the computer-controlled system will operate the condenser fans and pumps, thus achieving the lowest head pressure possible. Similar systems have saved between 5% and 10%. Columbia Colstor assumed a 7% savings. Again taking into account the interactive effects of these measures, a resultant 16.3% savings was calculated (1-(0.9)(0.93) = 16.3%). The compressors were assumed to operate 85% of the time during the 6-month processing season. Since usage is sporadic during the other 6-month non-processing season, no savings calculations were figured for this period. Therefore, the total savings for the new engine room were 3,449,273 kWh/year (based on 5,760 kW [7,725-hp] compressors, 0.85 usage factor for 6 months (180 days) per year, and 16.3% savings). Combining the savings from the existing and new engine rooms, total savings of 5,982,594 kWh/year should be realized. Given that Columbia Colstor processed 100,000,000 pounds of product in 1991, the savings equate to .13 kWh/kg (0.06 kWh/lb) of product.

The results of these engineering calculations are only as good as the assumptions made for the calculations. PNL made no effort to empirically verify these assumptions either for the general case or for the specific case of the Columbia Colstor installation.

2.1.2 Actual Annual Usage Calculation

The Actual Annual Usage (AAU) calculation is a simple calculation that was used to estimate the annual energy consumption with the RCS installed, and to attempt to verify the savings estimated by the engineering calculations. The portions of the contract and completion report that explain the AAU calculations are included in this report as Appendixes D and E. The AAU calculation references the savings calculations made from the engineering estimates, and is therefore also dependent on the appropriateness of the assumptions made in the engineering calculations. The major assumption behind the AAU calculation is that the driving component of the plant consumption will be the production in the freeze tunnels. The AAU calculation does not take the amount of product in storage or the outdoor temperature into account. Also, the AAU calculation derives savings that occur during processing season and extrapolates those savings throughout the entire year, even though processing only occurs during five months of the year. The determination of whether or not the expected savings are achieved is based on a comparison of the AAU with the Original Anticipated Annual Usage (OAAU). The OAAU is an estimate of what the electric consumption would be if the RCS was not installed, but the completion report does not adequately describe how the consumption figures that make up the OAAU were developed.

For Columbia Colstor, the AAU calculation was based upon two weeks of metered data for energy and freeze tunnel production in June, 1990. For that period, the total consumption was 970,032 kWh and the production of the freeze tunnel was 1,651,243 kg (3,640,367 pounds).[a] An estimate of the

(a) This production level, and all production levels presented in this impact evaluation, should be viewed with caution because of the way that Columbia Colstor measures production. Columbia Colstor measures production by weighing the amount of product that is delivered to storage. Any rework, rejects, or spillage are not included in the production total, so actual production through the freeze tunnels can sometimes be significantly higher than the amount weighed.

energy required for other (i.e., non-refrigeration) systems of 19,913 kWh (over the two-week period) was made to adjust the total consumption so that only refrigeration consumption is considered. This rendered, for this time period, an estimated refrigeration consumption of 0.575 kWh/kg (0.261 kWh/lb) of product. Based on the annual production of 45,359,000 kg (100,000,000 pounds) of product that was assumed in the completion report, and the estimated annual energy required for other systems of 477,911 kWh, the total anticipated annual energy use for June, 1990 through May, 1991 was 26,577,450 kWh. Of this total, 26,099,539 kWh was attributed to refrigeration. If this value is divided by the quantity of 1 minus the percent savings (16%, as estimated in the engineering calculations), then the estimate of what the total consumption would have been, had the RCS system not been installed, is:

$$AAU = \frac{26{,}099{,}539}{1 - 0.16} + 477{,}911 = 31{,}548{,}791 \text{ kWh}$$

The completion report gave the OAAU as 38,127,787 kWh. This would seem to imply, and the completion report states, that the savings are even higher than the engineering estimates indicate. However, the completion report also states that the original planned production was 54,431,000 kg (120,000,000 pounds), not 45,359,000 (100,000,000 pounds) as was then used in the AAU calculation. If consistency between OAAU and AAU calculations is adhered to, then the AAU should be calculated using 54,431,000 kg (120,000,000 pounds).

Doing the calculation again using an estimated annual production of 54,431,000 (120,000,000) results in an AAU of 37,762,967 kWh. This AAU is less than one percent different from the OAAU of 38,127,787 kWh. According to this calculation, only the estimated savings have been realized. It is important to realize that the AAU figure is not the true energy consumption with the RCS unit installed but rather the estimated energy consumption that would have resulted if the RCS unit were not installed assuming the savings with the unit is given by percent savings, which is based on the engineering calculations. It is also important to note that there is no documentation of how the OAAU was arrived at, only a table of numbers in the completion report.

A further comparison of the AAU estimate was made to the actual first year bills and freeze tunnel production for Columbia Colstor. The actual electric consumption for June, 1990 through May, 1991 was 25,817,000 kWh. This compares closely with the estimate based on the meter reading and 45,359,000 kg (100,000,000 pounds) of production. However, the total freeze tunnel production for this period was actually only 35,827,817 (78,987,037 pounds), which yields 0.721 kWh/kg (0.327 kWh/lb) of product as the annual ratio of electric consumption to production, a significantly higher number than the 0.575 kWh/kg (0.261 kWh/lb) indicated by the two-week metered data.

The discrepancy between these two ratios points to two additional weaknesses in the AAU calculation approach. First of all, a single two-week period does not seem sufficient to capture the true relationship between the electric consumption and the freeze tunnel production. In fact, the monthly ratios of energy to freeze tunnel production ranged from 0.370 kWh/kg (0.168 kWh/lb) for July, 1990 to 19.95 kWh/kg (9.05 kWh/lb) for March, 1991. This wide variation in actual ratios points out the second weakness of the AAU approach; namely, the effect of seasonal variations, in terms of the outdoor temperature and the agricultural production levels, and the effect of the use of the cold storage portion of the warehouse, are not taken into account.

2.1.3 Billing Data Calculations

Electric bills, outdoor temperature, and production data were used in an attempt to build regression models of the before- and after-retrofit electric consumption. The intent was to use these models to obtain an estimate of the actual effect of the RCS installation on the storage (as opposed to the freeze tunnel) refrigeration consumption, after correcting for both the differences in weather conditions and the substantial changes that were made to the Columbia Colstor facility at about the same time of the RCS installation. This technique cannot be used to estimate the savings for the freeze tunnels, as no pre-retrofit data exists for the freeze tunnels. The best that can be done is to separate the freeze tunnel consumption in the post-retrofit period in order to compare the warehouse refrigeration loads pre- and post-retrofit.

Using the models to compare the pre-RCS and post-RCS consumption, a savings estimate of 19% was calculated for the post-period with confidence intervals of -73% to 112%. A better estimate over the long term can be calculated using long-term average temperatures. In this case, a savings estimate of 17.4% with a 90% confidence intervals of -75% to 110% was calculated. Assuming that the post-period storage levels are representative of future storage levels, a savings of 4,491,507 kWh/year would result from the RCS installation with long-term average monthly temperatures. The confidence interval for this figure is from -19,411,983 kWh/year to 28,394,996 kWh/year with 90% confidence. The confidence intervals on these savings estimates are very large. This can be attributed to two aspects of the calculation, one which is general to any cold storage facility, and one which is particular to the circumstances surrounding the installation at this facility.

In general, the relationship between the outdoor air temperature and the pounds of food in storage could be described as collinear. When looking at the outdoor air temperatures versus month of the year, the pounds of food stored is seen to vary seasonally. The outside air temperature also varies seasonally. Figure 2.1 shows the variation of the temperature and pounds of food stored versus month of the year for a two-year period prior to the retrofit. Because of the seasonal variation of both outdoor

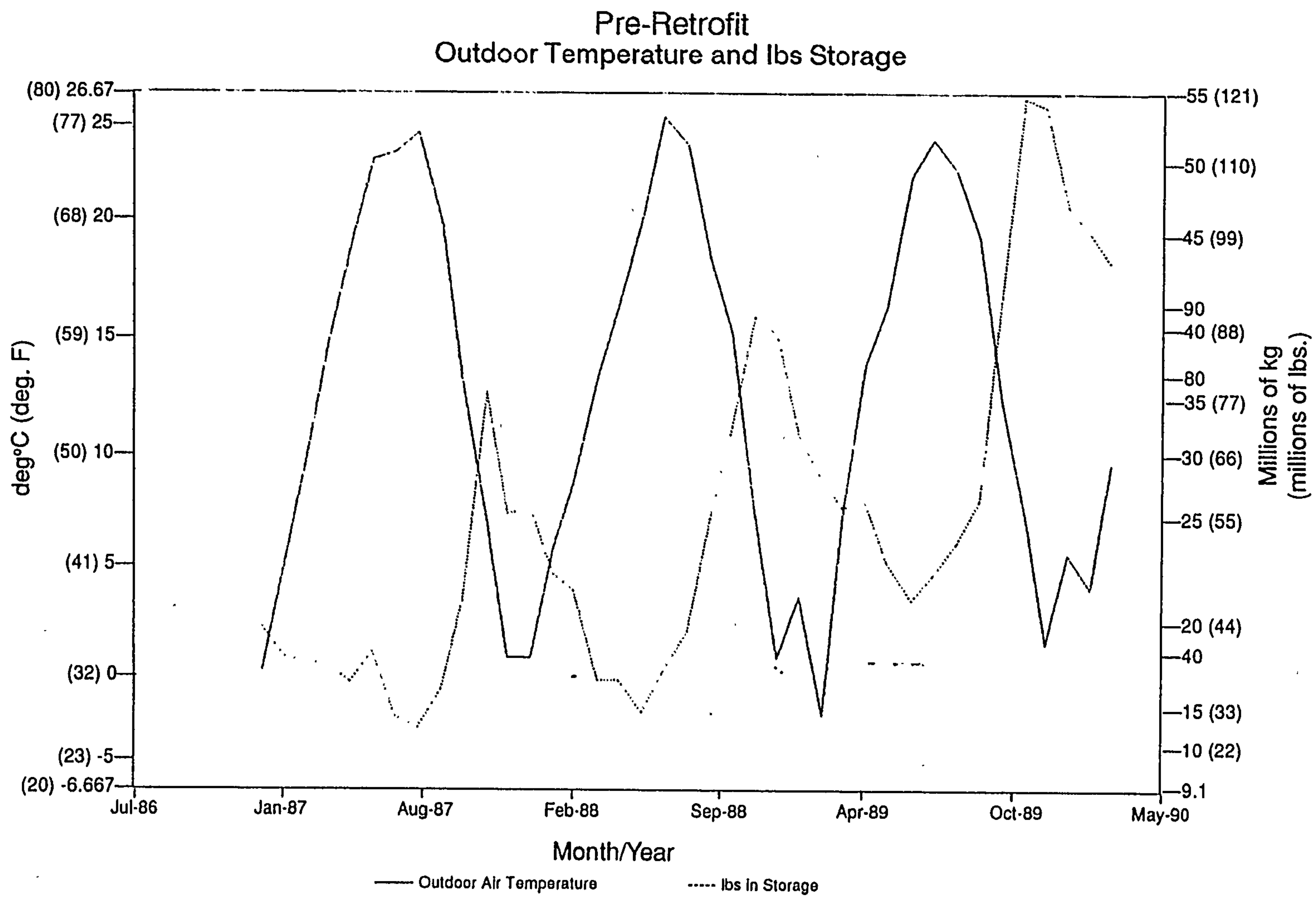

Figure 2.1. Pre-Retrofit Outdoor Temperature and lbs in Storage

air temperature and pounds of food stored, it is difficult to discern the outdoor air temperature effect from the effect of the quantity of food stored. The result is difficulty in modeling the process. The solution employed was to normalize the energy use to the pounds of food stored and to regress the data with respect to outdoor air temperature.

Further uncertainty and difficulties in the evaluation resulted from the addition of the freeze tunnels and increasing the floor area of the plant at approximately the same time as the RCS unit installation. It was difficult to differentiate the RCS effect from the effects of changing the floor area and adding freeze tunnels. The freeze tunnel effects were incorporated into the regression as a regression parameter to better model the facility. The data were normalized against floor area in an attempt to disaggregate this effect. The billing analysis is described in Appendix C.

2.1.4 Final Savings Estimate

The difficulties in determining the savings for this project have been alluded to in the report a number of times. The difficulties include the addition of the freeze tunnels and warehouse space at about the same time that the RCS was installed. These major changes precluded any straightforward comparison of consumption before and after the retrofit. In attempting to arrive at a savings estimate, the engineering calculations can be applied to the billed consumption for the first year. In order to do so, it must be assumed that the assumptions used in the engineering estimates of the savings were the same as what were used in the calculation of the OAAU (original anticipated annual consumption). If this is the case, then the 16% savings can be applied to the 25,817,000 kWh consumption for June, 1990 through May, 1991 to obtain an estimated first year savings of 4,130,700 kWh (0.47 aMW). This savings estimate is a conservative (because it is based on processing only about 35.8 million kg [79 million lbs] in the freeze tunnels), but defensible, estimate of energy savings from installing the RCS. Because these energy savings result from both cold storage and food processing, and because there are no data to separate the effects of these two activities at the plant, it is not possible to state the savings in kWh/unit of output.

Table 2.2 presents six savings estimates for this project. Note that each of the estimates offers cause to doubt its accuracy. In fact, there is no correct estimate of energy savings from this project with the data available to date. The largest difficulty in arriving at a savings estimate for this project is that the plant was expanded and freeze tunnels were added at the same time the RCS was installed. Other problems include production variations, weather variations, and variations in the amount of food in storage. Because it is the most conservative, energy savings of 4,130,700 kWh/yr, based on a combination of billing analysis and engineering calculations, was used in the levelized cost calculations for this impact evaluation.

Table 2.2. Comparison of Energy Savings Estimates

Estimation Source	Estimation Method	Savings Estimates (kWh/yr)			Notes
		Storage	Processing	Total Plant	
Project Proposal	Engineering Calculations	2,533,321	3,449,273	5,982,594	Based on processing 54,431,000 kg/yr (120,000,000 lb/yr) in freeze tunnels
Completion Report	AAU Approach	--	--	at least 5,982,594	Based on processing 45,359,000 kg/yr (100,000,000 lb/yr) in freeze tunnels and two weeks' data
Modified Completion Report	AAU Approach	--	--	6,579,996	Modified AAU result based on an inappropriate use of the AAU calculations and two weeks' data
Impact Evaluation	Combined Billing Analysis and Engineering Calculations	--	--	4,130,700	Based on actually processing 35,827,917 kg/yr (78,987,037 lb/yr) in freeze tunnels, which is well below expected production. Weather warmer than normal during billing period.
Impact Evaluation	Adjusted AAU Approach	--	--	5,982,600	Based on processing 54,431,000 kg/yr (120,000,000 lb/yr) in freeze tunnels and two weeks' data
Impact Evaluation	Billing Analysis	4,491,500	--	--	90% confidence internal ranges from -19,411,983 to 28,394,996 kWh/yr

2.1.5 Fuel Switching

Because Columbia Colstor operates an electrically powered freezing and cold storage plant, fuel switching is not an option. Therefore, no fuel switching resulted from installing this project.

2.2 Impacts to the Firm

2. ***If the project improved the productivity of the process, did the firm then increase output of the process to take advantage of the productivity improvement? Did the change in output result in a net increase or decrease in energy used by the process? Did the change in output cause changes in output at the firm's other plants in the region?***

Installation of this project did indeed improve the productivity of the production process by reducing the amount of energy required to store and process vegetables. However, because of the nature of the cold storage and processing business, Columbia Colstor is not able to increase production at its discretion to take advantage of the productivity improvement. Output at the plant is determined by the amount of vegetables Columbia Colstor's customers bring to the plant for processing and storage. This, in turn, is dictated by other factors such as crop yields and market conditions. Limited only by its plant's capacity, Columbia Colstor stores and processes as much vegetables as it can.

Columbia Colstor has two other plants in the Eastern Washington for storing vegetables, one in Kennewick and one in Wenatchee. Because of transportation costs, Columbia Colstor stores the vegetables at the plant with available storage capacity that is closest to the food processor.

2.3 Impacts to the Utility

3. ***What is the net impact to the serving utility in terms of electrical energy consumption (in kilowatt-hours) from implementing the project?***

Because there are no cogeneration or other complicating factors in this project, all of the energy savings from this project will be reflected in reduced load at the local utility, Grant County PUD.

2.4 Real Levelized Costs

4. ***What are the real levelized costs of the project from the perspectives of Bonneville and the region?***

Real levelized annual costs are used to compare the attractiveness of various projects or investment alternatives. The levelized cost is the annual cost that would be incurred over the life of the project, accounting for the time value of money. (See Appendix A for complete definitions and formula.) Levelized costs provide a single figure of merit for comparing energy conservation alternatives. In addition, levelized costs can be used to compare conservation projects with options for new generating capacity and to optimize the ranking of these options. Levelized costs are calculated from the perspectives of Bonneville and the region (Bonneville, Grant County PUD, and Columbia Colstor combined).

In the industrial sector, it is not possible to accurately predict the life of a project because any number of external factors could cause the project to have longer or shorter life than expected when it is installed. To allow comparisons of levelized costs among projects, all projects are assumed by PNL to have a life of 15 years for evaluation purposes. Even though some projects will have longer or shorter lives, 15 years is considered a conservative but likely life for typical projects in the industrial sector.

2.4.1 Bonneville Perspective

To determine the real levelized costs to Bonneville and to the region, the project costs (acquisition payment, capital costs, etc.) and the energy savings must be known, a discount rate and project life must be assumed. With energy savings of 4,130,700 kWh/yr, the project's levelized cost from Bonneville's perspective is 4.5 mills/kWh in 1993 dollars (see Appendix A). Bonneville's levelized cost decreases to 4.2 mills/kWh when transmission and distribution losses are considered. Including these losses allows comparison of conservation resources with generation that is measured at the point of production rather than at the site of the end user (point of delivery).

The levelized costs calculated in this impact evaluation include the acquisition payment by Bonneville as well as the estimated administrative and evaluation costs associated with this project.

2.4.2 Regional Perspective

To calculate the real levelized cost to the region, the costs to Bonneville, Grant County PUD, and Columbia Colstor are combined. The acquisition payment by Bonneville is included as a cost to Bonneville and as a reduction in cost to Columbia Colstor. This approach is taken because the acquisition payment has federal income tax consequences to the company and, therefore, is not a net zero cost to the region. The regional cost included Grant County PUD's cost to administer the project.

The calculated, real levelized costs to the region for acquiring annual energy savings of 4,130,700 kWh/yr is 7.6 mills/kWh saved. Including transmission and distribution losses, the levelized cost decreases to 7.1 mills/kWh saved.

2.5 Impact Attributable to Bonneville's Acquisition Payment

5. ***How much of the project's impact can be attributed to the acquisition payment from Bonneville?***

Columbia Colstor uses simple payback to select energy conservation projects, with a desired payback of less than three to five years. When this project was proposed to Bonneville, it was expected to cost Columbia Colstor $287,528 and result in electrical savings of $34,672 (usage and demand savings combined) per year for a simple payback of 8.3 years based solely on energy savings. This payback does not meet Columbia Colstor's selection criterion. With the acquisition payment from Bonneville, however, the simple payback would be slightly over three years [($287,528 - $180,375)/$34,672 = 3.1 years], well within the criterion.

The primary reason that Columbia Colstor installed this RCS is to obtain energy savings. With the addition of the freeze tunnels, energy conservation was becoming more important at the plant. Pacific Micro-Control mentioned the E$P acquisition payment in its sales pitch to Columbia Colstor to help sell the project.

Considering the facts presented above, we conclude that this project would not have been implemented without the acquisition payment from Bonneville and that all of the project's impact can be attributed to the acquisition payment from Bonneville.

3.0 Recommended Verification Procedure for Subsequent Refrigeration Control System Projects

In this chapter, the difficulties in verifying the savings from RCS projects are described, and an approach is suggested for verifying the savings from future RCS projects.

3.1 Difficulties of Verifying Savings from Refrigeration Control System Projects

Verifying the energy savings for refrigeration control systems at cold storage plants is particularly difficult for several reasons. Fundamentally, there is no single "correct" savings number for this type of energy conservation measure because the operation of these plants is never steady state. The amount of refrigeration required, and hence the savings from a RCS, varies from year to year as the amount of food processed and stored varies with changes in local farm output (both quantity and product mix). Weather variations from year to year also affect the amount of energy consumed for refrigeration. Because of these variations, the best that one can hope for in verifying savings from these projects is to come up with an estimate that reflects the long-term savings that are likely, assuming typical weather patterns and processing and storage loads.

Another reason that the savings from RCSs at cold storage plants are difficult to verify is because, as discussed in Section 2.1, seasonal weather variations are in phase with seasonal storage loads. Having these two key variations in phase makes it difficult to sort out their effects using statistical methods.

Another complicating factor is that door openings and closings significantly affect energy consumption, but recording their frequency and duration would place a major burden on the plant operator. Other similar complicating factors that affect energy consumption, but for which it would be burdensome to record reliable data, include incoming temperature and moisture content of product.

It was difficult to verify the savings from this project in particular because, concurrent with installing the RCS, the plant was expanded by adding more storage space and five freeze tunnels. This expansion prevented evaluators from establishing a historical baseline for the plant. With no baseline, numerous assumptions and engineering estimates are required to estimate energy savings, which decreases the accuracy of verified savings. This lack of a reliable baseline severely inhibited the accuracy of statistical methods.

3.2 Alternative Verification Procedure for Refrigeration Control System Projects

Because of all of the complicating variables described above, the preferred way to verify energy savings from a RCS at a cold storage plant is to compare energy consumption with and without the RCS under as similar conditions as possible. By operating a cold storage plant with and without its RCS operating, an energy consumption baseline can be determined concurrently with the post-installation energy consumption.

Even though RCSs can be switched on and off after installation, according to Columbia Colstor staff, this would not be practicable for several reasons. The most important reason is that switching off a plant's RCS introduces significant risk to plant operations and equipment. Product in storage could be ruined if a plant is operated improperly under manual control. Another reason that switching off a RCS is not practicable is because it is much more complicated than merely flipping a switch; it is actually quite complicated. Other, less severe reasons that this verification approach would not be practicable are that the cost of operating the plant would increase while the system is switched off and that refrigeration systems take hours to stabilize at different operating characteristics as the RCS is switched off and on.

Given that before-and-after-metering and switching RCSs off and on are not feasible for verifying the energy savings from RCSs, Columbia Colstor advocates engineering modelling, in conjunction with the advice of an industrial refrigeration expert, as the best approach for savings verification. Engineering models for industrial refrigeration systems are available from several sources. Columbia Colstor uses a model developed by a consultant for its own savings verifications, and the Washington State Energy Office also has a model for refrigeration systems (it is possible that these are the same, or different versions of the same, model).

Columbia Colstor has done some submetering to validate its refrigeration model. One drawback of engineering models for savings verification is that a lot of detailed information about the refrigeration system under study is required. Weather data must be obtained and some assumptions about product volumes must be made. Another drawback is that modelling is just that—modelling. Columbia Colstor also advocates that submetering be done along with modelling.

4.0 References

Spanner, G. E., D. R. Brown, D. R. Dixon, B. A. Garrett, R. W. Reilly, J. M. Roop, and S. A. Weakley. 1988. *Potential Techniques for Evaluating the Impact of Industrial Energy Conservation Projects under Bonneville's Energy $avings Plan*. Letter Report. PNL-6628, Pacific Northwest Laboratory, Richland, Washington.

Appendix A

Financial Evaluation Details

Appendix A

Financial Evaluation Details

A.1 Definitions

Real Levelized Cost - A single figure of merit that expresses the cost per unit of benefit (in this case, energy savings) accounting for the time value of money. This annualized cost (not the "adjusted system real levelized cost") would be constant over the entire project life. An infinite number of cash flow scenarios (costs incurred at different times in the project life) could result in the same annualized cost.

Real Levelized Cost to Bonneville Power Administration (Bonneville) - The annualized costs to Bonneville, direct and indirect, per unit of energy saved by the energy conservation project. Costs included are the acquisition payment and the program administrative costs, as well as the costs to evaluate the impact of this project.

Real Levelized Cost to the Region - The sum of annualized costs to Bonneville, Grant County PUD, and Columbia Colstor per unit of energy saved by the energy conservation project. This would include the same costs to Bonneville as above, plus the initial capital and ongoing incremental production costs to the firm. Any non-electrical savings that result from the project are not considered in this analysis.

A.2 Real Levelized Cost Formula

$$LC = \{[PVCI + PVICI + (PVOM + PVOTE) \bullet (1\text{-}itf) - PVD \bullet itf] / (1\text{-}itf)\} \bullet (CRF/AES)$$

where LC = levelized cost (real $)
PVCI = present value of initial capital costs
PVICI = present value of interim capital costs
PVOM = present value of operating and maintenance (O&M) costs
PVOTE = present value of one-time expenses
itf = combined state and federal income tax fraction

PVD = present value of depreciation

CRF = capital recovery factor (spreads the costs over the project life in real dollar terms)

AES = annual energy savings (kWh/yr).

A.3 General Assumptions

The following general assumptions were made in the real levelized cost calculations:

1. All cash flows are expressed in nominal terms (with inflation) and are discounted to present value at a nominal discount rate of 7.12% (combines a real discount rate of 3.0% and an inflation rate of 4.0%). The costs are annualized over the life of the project using the capital recovery factor at a real discount rate of 3.0%, resulting in real levelized costs.

2. Annual energy savings (kilowatt-hours/yr) are constant over the 15-year life of the project. This assumes no loss in efficiency of the equipment with time.

3. Transmission and distribution losses equal 7.5%, increasing the energy savings at the source (point of generation) by a corresponding 7.5%.

4. In the regional cost calculation, the acquisition payment from Bonneville is treated as a cost to Bonneville and, at the same time, a cash inflow to Columbia Colstor rather than a net zero cost. This is done because Columbia Colstor will incur a tax liability from the acquisition payment, thus part of it becomes a net cost to the region.

A.4 Bonneville Levelized Cost Calculations

Input: one-time expenses	
Acquisition payment paid (year 1)	= $180,375
Administrative and evaluation costs (years 0 and 1)	= $34,538
Tax rate	= 0%
Annual energy savings	= 4,130,700 kWh
Output: levelized cost	= 4.5 mills/kWh

A.5 Regional Levelized Cost Calculations (Bonneville + Grant County PUD + Columbia Colstor)

A. Columbia Colstor

Input:	initial capital (year 0)
Equipment	= $287,528
One-time expenses (revenues - year 1)	
Acquisition payment received	= ($180,375)
Tax rate	= 28.5%
Project life	= 15 years
Depreciation	= 5 years
Annual energy savings	= 4,130,700 kWh
Output: levelized cost	= 3.0 mills/kwh

B. Grant County PUD

Input:	
Administrative costs	= $3,963
Project life	= 15 years
Annual energy savings	= 4,130,700 kWh
Output: levelized cost	= 0.09 mills/kWh

C. Regional levelized cost = Bonneville levelized cost + Grant County PUD levelized cost + Columbia Colstor levelized cost

= 4.5 mills/kWh + 0.09 mills/kWh + 3.0 mills/kWh
= 7.6 mills/kWh

A.6 Levelized Costs Allowing for Transmission and Distribution Losses

Input: transmission and distribution losses	= 7.5%
Bonneville levelized cost = 4.5 mills/kWh/1.075	= 4.2 mills/kWh
Regional levelized cost = 7.6 mills/kWh/1.075	= 7.1 mills/kWh

Appendix B

Cover Sheet from Columbia Colstor's Proposal

Appendix B

Cover Sheet from Columbia Colstor's Proposal

Project Proposal
Requirement 2.

Cover Sheet

I. Sponsor Information

Name and Full Address of Sponsoring Entity

Columbia Colstor
P.O. Box 548
Quincy, WA 98848

II. Project Identification

Title Computer controlled refrigeration	Name and Title of Project Manager or Other Contact Bill Tracy, Plant Manager	
Location of Proposed Project Quincy, WA	Area Code and Telephone Number (509) 787-1577	
Standard Industrial Classification Code (SIC) 4222	Utility Service Area Grant Co. PUD	Portion of kWh Purchased From Servicing Utility 100 %

III. Project Summary

Brief Description of Proposed Project

A computer will be installed to control refigeration equipment in both an existing engine room and a new engine room.

Appendix C

Billing Analysis Energy Savings Estimate

Appendix C

Billing Analysis Energy Savings Estimate

Energy savings estimates were calculated using metered data from the periods before and after the RCS installation. Regression analysis was used to produce regression equations describing energy consumption in the pre- and post-retrofit periods.

The regression analysis proved to be more challenging than originally anticipated for a number of reasons. One confounding factor was that the outdoor air temperature and the pounds of food in storage both varied seasonally. This made it difficult to discern the effects of these two parameters. This relationship is shown in Figure 2.1 of the main text. In order to account for this relationship the data were normalized by the pounds of food processed before the regression was performed.

Other factors required special consideration. At approximately the same time the RCS was installed, freeze tunnels were also installed and the floor area of the plant was increased. Adding freeze tunnels and increasing the floor area of the plant allowed for more pounds of product to be processed and inherently changed the energy consumption of the plant. Changing the plant and production process in this way made it very difficult to differentiate the change in energy consumption due to the construction and process changes and that due to the RCS. In an attempt to account for the effect of the freeze tunnels on consumption, a regression parameter was included for the freeze tunnels in the post-period regression. The data were normalized against floor area in both the pre-RCS and post-RCS periods in an attempt to disaggregate the change in consumption due to the change in floor area.

The following regression equations were developed as approximations for the energy consumption of the building in the pre-RCS and post-RCS periods:

Pre-RCS Period

1. Consumption (kWh/day-sf-lb food stored) =

   1.67E-10 + 1.82E-11 • Outdoor Air Temperature

Post-RCS Period

2. Consumption (kWh/day-sf-lb food stored) =

   3.52E-10 + 1.09E-11 • Outdoor Air Temperature +
   2.76E-17 • lbs in freeze tunnels

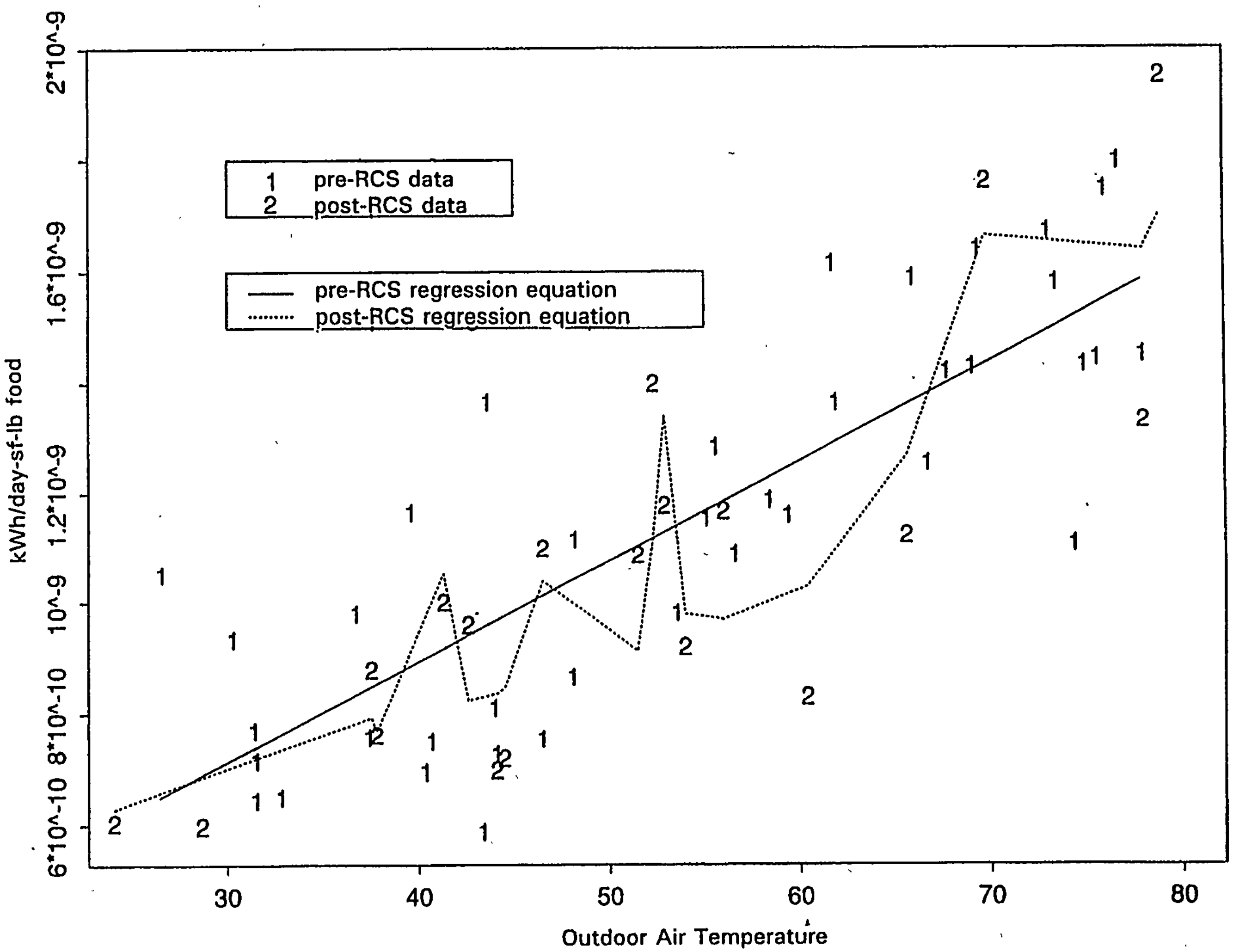

Figure C.1. Regression Equations and Actual Data

The regression equations and the actual data are shown in Figure C.1.

Using the outdoor air temperatures and the production levels for the post-RCS period, the energy saving estimates were calculated to be approximately 19% of the original energy consumption. Using long-term average temperatures to estimate future savings resulted in similar savings estimates (17.4%). Due to the many complicating factors involved in the analysis, the savings estimates have very large confidence intervals. With 90% confidence, the energy savings is between -73% and 112% of the pre-RCS period energy consumption level. Because of the large confidence intervals, the 19% savings estimate should be used with caution when estimating the savings potential of other RCS units.

Appendix D

Actual Annual Usage Calculations from the Bonneville/Grant PUD Contract, Exhibit C

COMPLETION REPORT REQUIREMENTS

After the inspection has been completed for each Project, a Completion Report shall be submitted by Grant to Bonneville. The report shall be page numbered and written in the following format and sent to the individual identified in section 9 of this Agreement.

1. Name and Full Address of Industry.

2. Project Title.

3. Project Description.
   Include a description of the Project, a list of the equipment which was installed, and the electric energy efficiency improvement accomplished.

4. Energy Savings Verification.

   (a) Definitions.

      (1) Energy from Other Systems, or EFOS, means energy consumed by systems other than the refrigeration system.

      (2) Original Anticipated Annual Usage, or OAAU, means the estimated sum of the annual energy consumption for the refrigeration portion of Columbia Colstor, including the 150,000 square foot expansion, plus estimated annual EFOS.

      (3) Actual Annual Usage or AAU, means a calculation of the actual annual energy consumption for the refrigeration portion of Columbia Colstor, including the 150,000 square foot expansion, plus annual EFOS. The AAU will be calculated using 2 weeks of meter readings and production data, and will include an adjustment to reflect the percent savings resulting from installation of the Project.

   (b) Calculation of Actual Annual Usage.
   The meter scheduled to be used at the plant is a recording type. A 2-week period will be selected during the first month that the plant is up and running, and product flow data will be recorded manually. The EFOS will be subtracted from the recorded meter data (since it is independent of production levels and unaffected by the computer) and the result will be extrapolated by way of the recorded production data. This figure will then be modified to reflect what the computer-control project is estimated to be saving. The EFOS will be added back in to arrive at the AAU figure.

This figure is the Actual Annual Usage figure and will then be compared to the Original Anticipated Annual Usage in order to verify the savings.

Mathematically, the AAU will be calculated as follows:

AAU = Actual Annual Usage
MR = Meter Readings (for two weeks)
AP = Actual Production (for two weeks)
EAP = Estimated Annual Production
PS = Percent savings from computer control project
EFOS = Energy from Other Systems

$$AAU = \frac{\left[\frac{MR-EFOS}{AP} (EAP) \right]}{(1-PS)} + EFOS$$

(c) Energy Savings Verification.
The AAU will be compared to the OAAU. If the AAU and the OAAU are nearly equal, then the Energy Savings are being realized, since the actual use is divided by 1 minus the estimated percentage savings from the Project. To the extent that the AAU differs from the OAAU, then the Energy Savings are either greater than or less than the original estimates.

5. Comments and Recommendations.
Provide a critique of the Project to identify possible improvements in equipment or procedures for similar Projects.

6. Certification by Grant.
Acting as a duly authorized representative of Grant, I certify that the Project has been inspected, that all equipment has been installed in accordance with the Proposal, the Project is operating, and that the Energy Savings estimate and verification performed in section 4 above is reasonable, based on generally accepted and customary engineering practice.

Public Utility District No. 2
of Grant County, Washington

By ______________________________

Title ______________________________

Date ______________________________

Appendix E

Actual Annual Usage Calculations from Columbia Colstor's Completion Report

Appendix E

Actual Annual Usage Calculations from Columbia Colstor's Completion Report

The increase in efficiency caused by the computer can be measured by dividing the Original Anticipated Annual Usage and the Actual Annual Usage by the Estimated Annual Production, and comparing the results. (see below for details on these numbers)

OAAU/EAP = 38,127,787 kWh/100,000,000 pounds = .38 kWh/pound

AAU/EAP = 30,826,216 kWh/100,000,000 pounds = .31 kWh/pound

~~Efficiency improved by 18%.~~ 16% increase in refrigeration eff → 18% improved kWh/# Ok 29Aug 91 see Atkinson memo 27 Aug

ENERGY SAVINGS VERIFICATION

Definitions

Energy from other systems (EFOS) - A tabulation of these numbers is on page 10. Most of these systems run on a flat basis throughout the year. For the two week calculation, the annual total of 477,911 was divided by 24. adjusts annual use to the two wk period

Original Anticipated Annual Usage (OAAU) - The OAAU consists of the total of the monthly projections for the refrigeration system, which are shown on page 10, plus the EFOS. The OAAU therefore is: 37,649,876 + 477,911 = 38,127,787 kWh.

Actual Annual Usage (AAU) - This is the actual kwh consumption for the year, calculated by extrapolating the highlighted data above and below by the formula in Exhibit C. The calculation is shown below.

Calculation of Actual Annual Usage

Meter Readings (MR) - Output from a recording meter is included as a Lotus file on the enclosed disk. The last compressor was connected to the computer in April. Production was nominal in May, and an accurate calculation of AAU was impossible. Therefore, energy consumption data for two weeks in June is what was used in the analysis. The average of the fifteen minute recordings is multiplied by the total number of hours in the period to arrive at the total consumption for the period. MR = (2,887 average kW)(24 hours/day)(14 days) = 970,032 kWh.

Actual Production (AP) - Actual production for the period was 3,640,367 pounds of product.

Estimated Annual Production (EAP) - Originally, Colstor and Simplot planned to process 120,000,000 pounds of product in 1991. Crop and market conditions have since reduced this scheduled number to 100,000,000. Projections for 1992 and beyond are for 140,000,000 pounds.

Percent Savings from computer control project (PS) - Based on the estimate of energy savings from the proposal, and the OAAU, the percent savings are projected to be 5,982,594/38,127,787 = 16%.

The AAU is as calculated below:

$$AAU = \frac{\frac{MR-EFOS}{AP}\ (EAP)}{(1-PS)} + EFOS$$

inserting the above highlighted numbers into the formula yields:

$$AAU = \frac{\frac{970,032-19,913}{3,640,367}\ (100,000,000)}{(1-.\sout{14})\ .16} + 477,911 = \sout{30,826,216}\ 31,548,791\ kWh$$

per Atkinson memo 29 Aug 91 ok

Energy Savings Verification

Per the above verification results, it is reasonable to conclude that the system is saving more than the 16% originally projected. How much more is difficult to calculate. Although the AAU is significantly less than the OAAU, it is difficult to tell whether this is due to the system saving more energy than projected, or because production levels which are slightly less than projected cause the formula to be skewed. In any case, the results lend credence to the conservative savings figure of 5,982,594 kWh calculated in the project proposal.

Calculated savings = 38,127,787 − 31,548,791 = 6,579,996 kWh
Evaluation will need to get in and do their stuff to see if this methodology works.