Managing Time-of-Use Electrical Rates in Cooling Facilities

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Abstract. The feasibility of four methods of managing time-of-use electricity rates in produce cooling facilities is evaluated. Switching from propane to electric lift trucks, installing a generator set, lengthening the cooling cycle, and installing a thermal energy storage system are all technically feasible and have been used in commercial facilities. Lengthening cooling time can sometimes be accomplished without any equipment changes, and is financially attractive. The cost of installing a generator set or thermal energy storage equipment can be paid back rapidly under some conditions. Electric lift trucks are not cost effective solely on energy cost savings, although electric lifts do not produce ethylene or carbon monoxide and may be justified on the basis of product quality and worker safety improvement.

Introduction

Harvest for fresh market commodities usually begins at dawn and continues for six to eight hours. Several hours may be required for staging the produce in the field and one or two hours of transportation time to the cooling facility. The first product is often placed on the precooler from 10:00 a.m. to noon and product will be added to the cooler for the next six to eight hours. This means that the bulk of the refrigeration load occurs from noon to 6:00 p.m. which corresponds to the peak rate period for electricity. We have identified four options that can be used in cooling operations to reduce the amount of electricity purchased during the peak rate period.

Using electric lift trucks in a refrigerated area reduces electricity demand because they produce less waste heat than propane lift trucks and their batteries can be charged during off-peak rate periods. Since the advent of batteries that can last a full 8-hour shift, even with a significant amount of product lifting, many cold storage and forced-air cooling operations have shifted to electric lift trucks. Also, electric lift trucks do not have engine emissions like propane powered lift trucks do. Ethylene in engine exhaust can cause premature ripening and other postharvest problems in some perishable products. Carbon monoxide emissions in an enclosed facility can be a worker safety hazard.

Generator sets can be used to produce electricity on site during peak rate periods. A few cooling operations have purchased equipment for this purpose (Micheli, 1986). The generator set also serves as a standby power supply if there should be an interruption in utility power.

Thermal energy storage systems have been installed by a number of operations to reduce their on-peak demand (EPRI, 1985). Usually the system consists of a water filled tank with an evaporator coil situated below the water line. During nighttime hours, the refrigeration system builds up ice on the coil. During the day, water at nearly 0° C can be used for refrigeration effect. This technique has been used in some forced-air coolers in the past (Mitchell et al., 1972). Another system uses ice making equipment to produce and store ice during off-peak hours. The ice is then used in package ice cooling, where the ice is placed in the box of produce and is used for product cooling. This system is already in wide spread use for cooling broccoli.

Thermal energy storage can also reduce energy and refrigeration costs. Cool night air temperatures allow refrigeration equipment to operate more efficiently than it does in the day. Shifting refrigeration use to the night will reduce refrigeration energy use. Reducing overall peak refrigeration requirements will allow the use of less compressor and condenser capacity and can be a significant cost saving in new installations.

Extending the length of the cooling cycle is a technique that can be used in a forced-air cooling facility. If a facility has excess cooling capacity during the nighttime hours, the cooling fan capacity can be reduced to increase cooling times. Slower air flow through the product can significantly reduce peak refrigeration load and shift some refrigeration demand to the off-peak rate period. The need for less fan capacity can result in less overall energy needed for the cooling operation. Slower cooling will not significantly reduce the quality of

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many commodities. Although, there are a few crops, such as strawberries, that should be cooled as quickly as possible.

The goal of this study is to evaluate the technical and financial feasibility of the four options for shifting load from the peak rate period in cooling facilities for fresh market commodities.

Methods

All of the systems analyzed have been used in commercial coolers. The technical feasibility was investigated by interviewing the owners and installers or suppliers of the equipment. These people also provided information on capital and operating costs for the equipment, which served as a basis for a before tax, net present value financial analysis (Newman, 1976). Results of the analysis were expressed in terms of internal rate of return (IRR), year of payback, and annualized savings. In each case, a specific example was selected to represent the financial effects of a technology and to illustrate the important effects of the techniques. Table 1 is summary description of the example cases.

For the electric lift truck example, we assumed the purchase of a 2,300 kg (5,000 lb) capacity lift truck that cost $29,900 plus $6,000 for a battery and $2,000 for a charger. The lift truck had a life of 28,000 h and the battery would have to be replaced after 1500 charge cycles. Maintenance costs for the electric lift were assumed to be $1.00 per hour of operation. A comparable propane powered lift truck cost $23,600. It had a life of 28,000 h with an engine life of 14,000 h. Maintenance costs for propane lifts were twice that of electric lifts, at $2.00 per h. We assumed propane costs of $0.13 per L ($0.50 per U.S. gallon). Cost of removing the waste heat produced by the lifts was based on the lifts operating in refrigerated space 80% of their 8-hour day. The cooling facility operated for five months per year.

An existing 250 kW generator set installed with a forced-air cooler was used as an example for generating electricity on site during peak rate periods. A generator set of this size, powered with natural gas or diesel fuel, costs $28,000. Equipment larger than 100 kW costs $110 to $120 per kW regardless of size, so this analysis applies to most all sizes of coolers. Based on manufacturer's data, the equipment had an assumed life of 14,000 h and had maintenance costs of $2.52 per h of operation. In addition, special switch gear is required to connect the generator to the in-house wiring which is needed to allow the use of utility power in case of equipment problems. This costs $14,000. The cost could be significantly lower if the switching capability had been installed during initial construction. Fuel is the major cost in operating a generator set. We evaluated the sensitivity of fuel cost on project finances by assuming a fuel cost $0.13 or $0.20 per L. This is equal to natural gas costs of $3.80/Gj ($3.60/million Btu) or $5.70/Gj, respectively. The generator was operated during the peak and partial-peak rate periods of the day.

The financial feasibility of a thermal energy storage (TES) system was based on retrofitting a vacuum cooler with a chilled-water, ice building system (PG&E, 1985). The cooler had a capacity of 640 cartons of lettuce (a carton weighs about 27 kg (60 lb)). The chilled water from the ice builder was used in an added condenser coil inside the vacuum cooler. The existing refrigerant cooling coil was not used. The ice building system and additional coil cost $94,000. The system was assumed to have a life of 20 yr. and annual maintenance costs of 1% of the capital cost. The TES system allowed the refrigeration system to operate much more during the cool night hours compared with a conventional vacuum cooler that would operate only during the daytime. This increased the efficiency of the refrigeration system to a coefficient of performance of 6.3 compared with 4.4 without TES. The financial feasibility of building a TES system into a new cooler was also estimated. This would significantly reduce the cost of the refrigeration equipment because less high-pressure side capacity (compressor, condenser, and associated piping) would need to be installed. Based on test data for the cooler, 35% less high pressure capacity would need to be installed, with a cost of $340/kW ($1,200/ton).

We have assumed that the system for extending cooling cycle (ECC) in a forced air cooler had no initial cost because it was accomplished by just reducing the number of fans that are operated during the cooling cycle. If an operation were used to full capacity 24 h per day, then this technique would require installing more cooling capacity and the financial analysis would be completely different. As an example, we calculated the effect of cooling 320 bins of peaches (a bin of fruit weighs about 500 kg) in a forced-air cooler. In the fast cooling case, 40 bins were added to the cooler each hour and each bin required 6 h to cool, resulting in a total cooler operation time of 13 h. For the slow cooling example, 40 bins were added per h and each bin required 15 h to cool, resulting in a total cooler operation time of 22 h.

For all examples we assumed a utility rate currently in use in California. Electricity costs $0.07/kW h from 12:30 p.m. to 6:00 p.m., the peak rate period; $0.04/kW h from 9:30 p.m. to 8:30 a.m.; and just under $0.07/kW h during the rest of the daytime hours. In addition, a demand charge of $10.47/kW was levied for electricity demand during the peak rate period. A $200/kW rebate is sometimes offered to customers who install equipment to shift load. We assumed that the rebate would be available for the lift truck and the retrofit thermal energy storage examples. Loan rate and discount rate were set at 11%. Loan period was six years for all equipment except the TES system which was assumed to be 10 years. Tax and insurance cost was assumed to be 2% of capital costs.

Results and Discussion

All of the techniques have the potential to reduce peak demand, as seen in Table 1. The use of an electric lift truck shifts the smallest amount of load at only 4.5 kW per lift. However, many operations use several lifts so the total shift might be as high as

Table 1. Summary of example cases used to evaluate methods of reducing electricity cost under time-of-use rates

Example case	Cooling method	Other compatible cooling methods	Initial cost ($)	Demand reduction (Kw)	Advantages other than time-of-use effects
Electric lift truck	Forced-air	None	37,900	4.5/lift	No engine emissions
Generator set	Forced-air	All others	42,000	250	Standby power
Thermal energy storage	Vacuum cooler	All others	94,000	161	Less refrigeration capacity required, increased refrigeration efficiency
Extending cooling cycle	Forced-air	None	0	52	Reduces energy use

25 to 30 kW. The other three techniques can reduce peak demand by at least several times this amount.

The financial analysis, summarized in Table 2, shows a wide difference between the various techniques. Of course, extending the cooling cycle has the best financial return because there is no initial cost to incorporate this technique in an operation. Any utility cost savings are direct profit to the operator.

Figure 1 shows the effect of ECC on refrigeration demand for product cooling in the example case. The fast cooling rate results in a peak refrigeration demand of slightly more than 560 kW (160 tons) and the demand is during the peak rate period. The slower coolng rate also has a peak demand during the peak rate period, but it is slightly more than 390 kW. This results in a 50 kW reduction in peak electricity demand and an annual savings of $2,700. In this example, the slow cooling rate still allows for product to be unloaded (first bins loaded on the cooler are finished at midnight) in preparation for the next day's cooling.

ECC is not suitable for hydrocooling and vacuum cooling where cooling times are short, usually less than one hour. With these coolers the only way to extend the cooling into the off peak hours would be to partially cool the product and store it until later in the day when cooling could be finished. This would require rehandling the product and would not be viewed as feasible by commercial operators. ECC is well suited for forced-air cooling produce, such as apples, grapes, and stone fruit, that can withstand delayed cooling. An added advantage of this technique is that it may require less fan energy than fast cooling, although we did not figure this into the financial analysis of the example.

The next most profitable technique is to install a diesel generator set. Under most conditions the best return is obtained by operating the generator set during the peak and partial-peak periods. This can result in an IRR of 175% and a payback in the first year of operation. However, the cost of operating a generator is very sensitive to the cost of fuel and the above figures are based on purchasing fuel for $0.13 per L ($0.50 U.S. per gallon). If fuel cost is assumed to be $0.20 per L, the IRR drops to 50% and the project cost is paid back in year 5. Fuel costs greater than $0.13 per L may make the project fairly unattractive. The analysis assumed an overall generator set efficiency of 25%. However, there are generator sets that operate at efficiencies as high as 30%. Purchasing an engine with a high efficiency will allow the operation to be profitable at costs above $0.20 per L.

Generators have several other advantages. Diesel engines can be set up to operate in a dual fuel mode. This allows the engine to run completely on diesel fuel or receive up to 90% of its energy from a gaseous fuel like propane or natural gas. In recent years, the relative cost and sometimes the supply of energy sources has fluctuated. This equipment will allow an operator to shop around and use the cheapest source of energy.

This system is suitable for all types of cooling systems: forced-air, hydro, vacuum, and ice cooling. Some of these operations are designed to be portable. Particularly vacuum and hydrocoolers may be moved to two or three locations during the year as production areas change. Engine driven generators can easily be made portable and will work well with a portable cooling system. It also has the advantage of providing standby power in case of a utility power interruption.

Ethylene produced by the engine may damage some commodities and special precautions may need to be taken to prevent quality loss in ethylene sensitive commodities. In some areas, air pollution permits may be needed to operate the generators. Some utility companies may assess special charges or restrict the rates that are offered customers that generate their own electricity.

Retrofitting a thermal energy storage system to an existing vacuum cooler appears to be marginally financially feasible. It has an IRR of only 17% and a

Table 2. Financial effects of four options for reducing peak-rate period electricity demand in agricultural cooling operations

	Electric lift truck	Generator set		Thermal energy storage		Extending[b] cooling cycle
		$0.13/L[a]	$0.20/L	Retrofit	New	
IIR (%)	5–8	175	47	17	430	Very high
Year of pay back	None	1	5	5	1	Very quick
Annualized savings	($540)[c]	$9,700	$3,700	$3,500	$9,400	$2,700

[a] $1.00/L = $3.78/gallon.
[b] There is no investment cost for extending cooling cycle under the assumptions we made, so all utility savings are net profit. Internal rate of return and year of pay back are not meaningful in this situation.
[c] Parenthesis indicate negative savings or an annual cost.

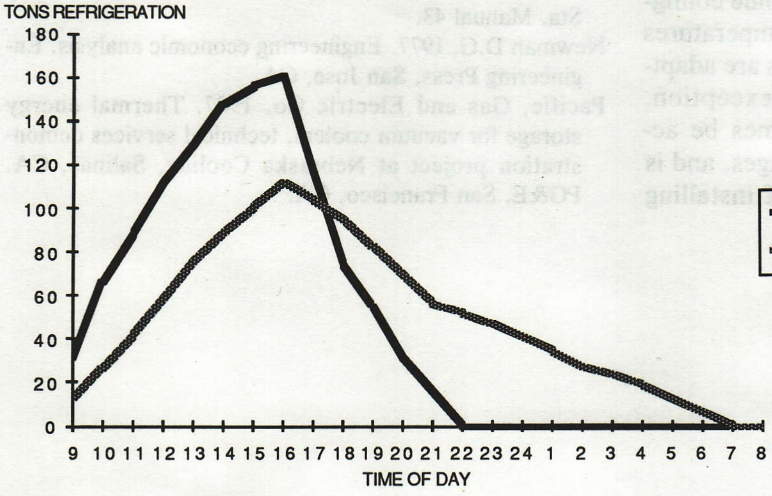

Fig. 1. Effect of extending the cooling cycle on refrigeration capacity needed to cool fruit based on forced-air cooling 320 bins of peaches (500 kg per bin). Forty bins are added to cooler per hour and bins take 6 or 15 hours to cool.

payback in the fifth year of operation. The project was credited with a 161 kW load shift. A $200/kW rebate from the utility reduces installation cost by one third and without this, the project would not be financially feasible. If this equipment were installed on a new vacuum cooler, the load shifting would allow installation of about 260 kW (75 tons) less refrigeration capacity (less high pressure side equipment only). The reduction in refrigeration equipment nearly equals the cost of the thermal energy storage equipment and the financial feasibility is much better than the retrofit case.

The main limitation of chilled water TES systems is that they can not easily produce water temperatures below 0° C. In a forced-air cooling system, the cooling air will be 0.25° to 1° C above this and the product can not be cooled to below 1° to 2° C. Some products such as strawberries must be cooled to 0° C and can not be properly cooled with this type of TES system. The experimental vacuum cooler was able to cool product to 2° to 3° C, which is not quite low enough for many vacuum cooled products. Temperatures lower than this require the use of the refrigerant cooled condensing coils, and this would increase the demand during the peak rate period and reduce the savings of the system. Hydrocoolers are usually operated with 0° C water and should be well suited to a chilled water TES system.

It may be possible to use TES systems that produce ice in the cooling systems that do not work well with chilled water systems. Ice could be used directly as the cooling medium in forced air and vacuum cooling operations and result in product temperatures at or below 0° C.

Purchasing electric forklifts to replace propane powered lift trucks is not financially attractive on the basis of capital and direct operating costs. The $14,300 extra cost of an electric lift cannot be repaid by the lower maintenance, fuel, and refrigeration cost savings. However, many operators of forced-air coolers have switched to electric. Some have done so because electric lifts do not produce ethylene gas, which can prematurely ripen or damage produce. Electric lifts also do not produce carbon monoxide, which has caused injuries and accidents when it is allowed to build up in an enclosed facility.

Conclusions

All of the methods of shifting electricity demand of produce cooling facilities to off-peak periods have been used commercially and are feasible under the right circumstances. Lengthening cooling time and using electric forklifts are suitable for forced-air cooling facilities. Thermal energy storage system can be used in all types of coolers, but some configurations may not produce low enough temperatures for some commodities. Diesel generators are adaptable to all cooling methods without exception. Lengthening cooling times can sometimes be accomplished without any equipment changes, and is very financially attractive. The cost of installing diesel generators can be paid back rapidly when fuel costs are low. Thermal energy storage can be very cost effective when it is designed into a new facility. Electric lift trucks are not financially feasible solely on their energy cost saving effects.

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