Energy Efficiency Opportunities in Fresh Fruit and Vegetable Processing/Cold Storage Facilities

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ABSTRACT

In this paper, the results from detailed plant-wide energy audits of seven fresh fruit and vegetable processing plants in California will be described and potential savings opportunities for large and small size processing plants will be addressed. The details of fresh fruit and vegetable processing from a viewpoint of energy consumption and operating cost will be discussed, and potential measures for energy and cost savings will be outlined.

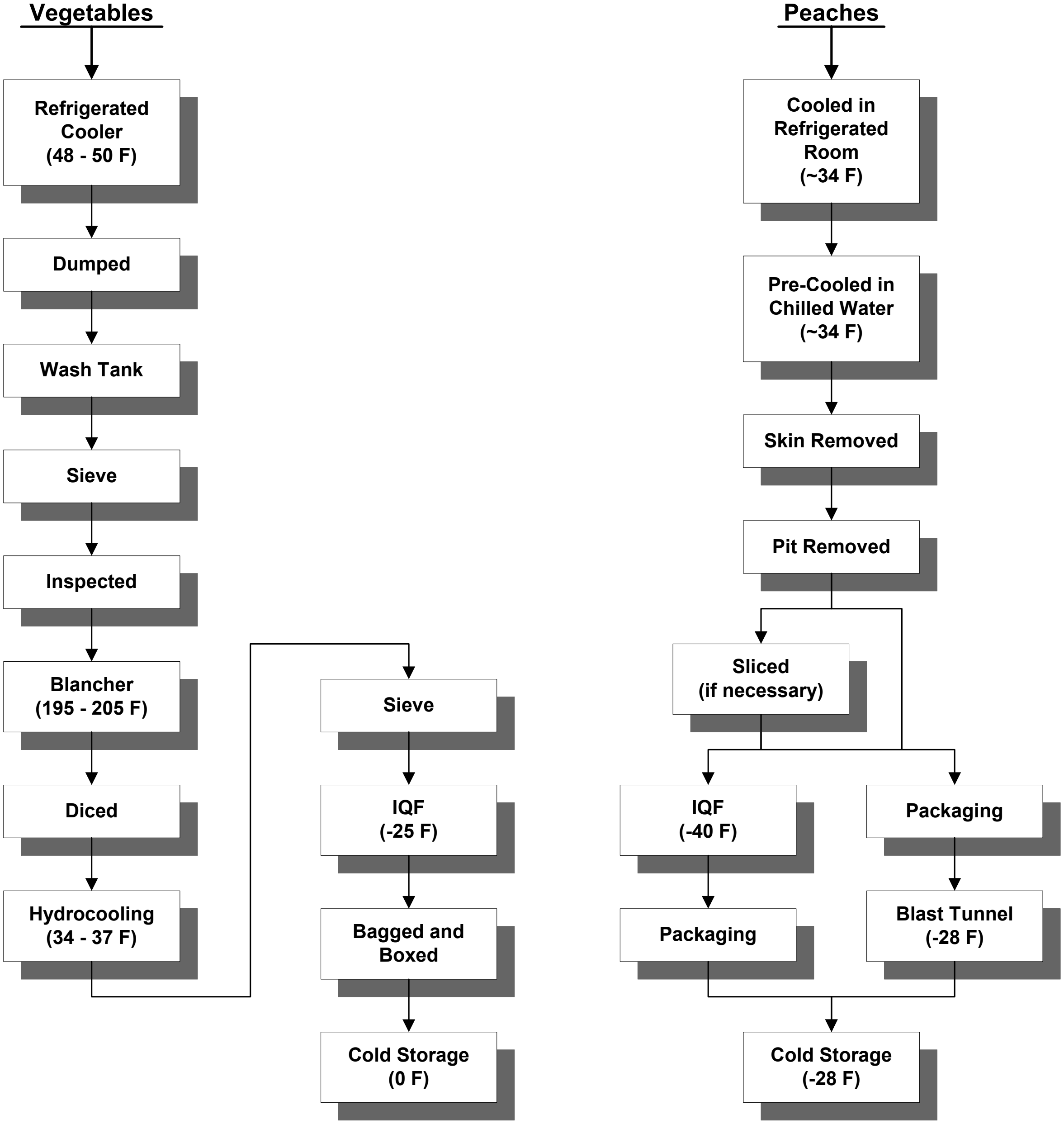
Introduction

The initial cooling, processing, and cold storage of fresh fruit and vegetables is among the most energy intensive segments of the food industry. Significant levels of refrigeration and heating are needed to slow down spoilage and maintain preharvest freshness and flavor of ripe fruit and vegetables. Cooling the fresh fruit and vegetables before processing removes the "field" heat from the freshly harvested products in time to inhibit decay and help maintain moisture content, sugars, vitamins, and starches. Blanching of fresh vegetables such as asparagus, broccoli, and cauliflower helps maintain product texture and color. The quick freezing of processed fresh fruit and vegetables helps maintain the quality, nutritional value, and physical properties for extended periods. The refrigeration systems, especially for the fruit processors, usually operate at their heaviest load during the summer daytime hours when electrical costs and outdoor temperatures are the highest.

According to the U. S. Census Bureau, the U.S. had 235 frozen fruit, juice, and vegetable processing facilities in 2002 (NAICS 311411) that employed approximately 38,000 workers. Processing fresh fruit and vegetables is a highly energy intensive industry. In 2002 the 235 processing plants consumed an estimated 2,925,970,000 kWh of electricity, and had energy costs totaling more than $276 million (includes electricity and other fuels). In 2002 the total value of shipments was more than $9 billion. The state of California has 48 frozen fruits and vegetable processing plants that consume approximately 329.8 million kWh of electricity and 38.7 million therms of natural gas per year (Sullivan, 1999).

The majority of the electricity consumed at such plants is commonly by ammonia refrigeration. Other electric using devices are lighting, compressed air systems, hydraulic pumps and other process drive motors. In most cases natural gas is the only fossil fuel used at these plants and with few exceptions it is used to produce steam for processing (e.g. blanching) and sanitation. Diagrams showing vegetable processing and fruit processing are shown in Figure 1 on the following page. A pie chart showing the annual electrical energy usage of a vegetable processor by system and function is shown in Figure 2, while a similar pie chart for a fruit processor is shown in Figure 3.

Figure 1. Vegetable Processing and Fruit Processing Flow Diagrams



Refrigeration Systems

Each of the facilities that were audited had multiple ammonia refrigeration systems. The refrigeration systems typically support three evaporator temperatures: 35 °F for water chilling, -5 to 0 °F for frozen storage, and -40 to -25 °F for quick freezing.

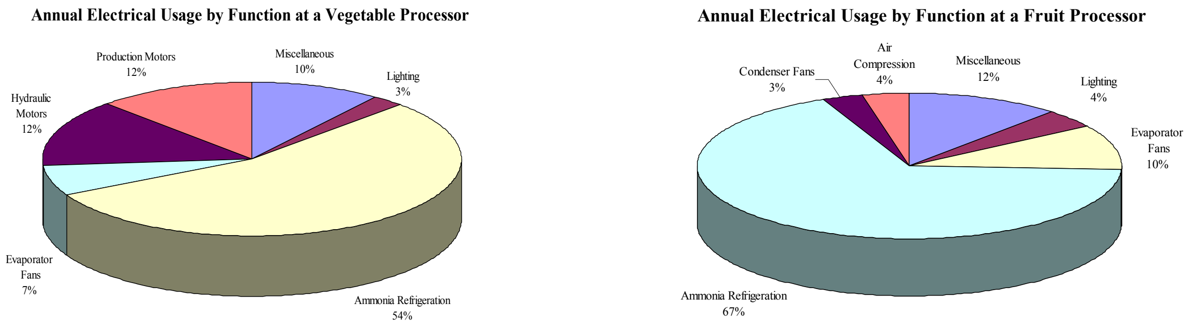
The fruit and vegetables that arrive with significant "field heat" are typically held in refrigerated rooms to cool before being processed. The rooms typically have forced-air coil evaporators operating at a temperature of 33 to 35°F. Depending on their initial temperature the fruit and vegetables may spend several hours to days room cooling before being processed.

Another form of above freezing refrigeration that is common in these fresh fruit and vegetable processors is hydrocooling. Hydrocooling may be accomplished by way of a shower-type unit or by an immersion-type unit. In both cases chilled water is typically produced in plate heat exchangers and put in direct contact with the fruit or vegetable. The chilled water evaporator is controlled to operate as close to freezing as possible. Hydrocooling is employed to cool fruit and vegetables just prior to freezing. Using hydrocooling to cool produce down to 33 - 35 °F is much more efficient use of energy than it is to use the evaporators (-40 to -25 °F) in blast tunnels or individual quick freezers (IQFs).

Freezing is an effective method for preserving the physical and nutritional value of food for extended periods of time. A significant portion of a plant's energy is used to reduce the fruit and vegetables temperature below freezing. Air is cooled by an evaporator at -40 to -25 °F and blown by fans to pull heat from the product. Two types of air-blast freezers are used in this industry: stationary freezing tunnels (a.k.a. blast tunnels) and belt freezers (e.g. spiral freezers). Blast tunnels are batch freezing process, while belt freezers are a continuous freezing process. The ammonia refrigeration necessary to produce freezing air at -40 to -25 °F is the major user of energy in the process, but the fan power needed to push the air past the product at relatively high velocities is also a significant consumer of electricity.

Cold storage is the least energy intensive portion of the plant's refrigeration system. Cold storage rooms are typically held at -5 to 0 °F by forced-air evaporators. Because the product arrives from the freezing process at or below the cold room temperature, most of the cooling load is from internal sources (evaporator fans, high bay lighting) and external sources such as outside air infiltration through doors and heat transfer through room shell.

Figures 2 & 3. Annual Electric Energy Usage by Function for a Vegetable Processor and a Fruit Processor


Annual Electrical Usage by Function at a Vegetable Processor

Annual Electrical Usage by Function at a Fruit Processor

Heating Processes

Natural gas fired boilers are used to produce steam for sanitization, blanching, and steam peeling. Saturated steam is produced at 80 to 100 psig. The largest user of steam at a fresh fruit and vegetable processing plant is steam for sanitation. Typically, one to four hours are spent sanitizing the processing equipment and area with steam and a sanitizing agent. At plants where row crops, such as broccoli are processed, they are blanched (partially cooked) with steam before being frozen and packaged. The residual heat in the vegetable after blanching contributes to the plant refrigeration load. After blanching, the vegetables are cooled with chilled water or a combination of clean plant water and chilled water. Some vegetables, such as onions and bell peppers, are steam peeled, which is the direct application of steam to a vegetable with the purpose of soften its outer skin for later removal. Some specialty processors may roast vegetables such as bell peppers and onions. The whole vegetables are roasted with exposure to a gas-flame in a rotating steel cylinder.

Other Energy Consuming Systems

Other users of energy are pumps for process cooling water and wastewater treatment, hydraulic pumps for process machinery and conveyors, air compressors, and lighting in processing areas and cold storage rooms.

Major Opportunities to Cut Energy Operating Costs

For the seven fruit and vegetable processing plants analyzed and included in this paper, the energy consumption, energy costs, and refrigeration capacity of the plants varied from very large (37.1 million kWh per year) to very small (4.8 million kWh per year). Two of the audited plants are large enough to be separated into their own class, while the five smaller plants are of the same comparable size (i.e. energy usage and electric demand). The average characteristics of both "Large" and "Small" processing plants are shown in Table 1 below.

TABLE 1 - SUMMARY OF LARGE AND SMALL PLANT CHARACTERISTICS

Average Value	Large Plant	Small Plant
Annual Electrical Energy Usage	29,000,000 kWh/yr	7,900,000 kWh/yr
Maximum Electrical Demand	6,350 kW	1,780 kW
Annual Gas Energy Usage	1,300,000 therms/yr	119,000 therms/yr
Annual Total Energy Costs	$3,075,000/yr	$1,075,000/yr
Refrigeration Compressor Capacity	8,000 hp	2,300 hp
Covered Area	625,000 sq. ft.	139,000 sq. ft.

The large plants are characterized by huge processing capacity (up to 1 million pounds of produce per day) and processing dedicated to specific crops (e.g. tree fruits such as peaches and apricots). These large plants have very large ammonia refrigeration plants that include newer, more efficient compressors and evaporative condensers, and the equipment is better controlled and operated for lower energy consumption.

The smaller processing plants are characterized by processing lines designed to handle multiple crops, depending on the season. These smaller plants typically have multiple ammonia refrigeration systems (up to 4 at one plant) that are dedicated to a particular part of the production process (e.g. cold storage or an IQF). The ammonia refrigeration plants are often more than 40 years old, often lack instrumentation and monitoring equipment that can be read from a central location, and relied more on operator knowledge and experience for system performance than on automated controls.

Since the focus of the plant audits was limited to energy consumption, plant production figures were not made available to the audit team members. Benchmarking of the plants' productivity was not included in the original analyses and for that reason cannot be included in this paper. The major opportunities to cut operating energy costs are discussed by system category as follows.

Refrigeration System Controls & Optimization

Improvements in system controls and other optimizations have the benefit of increasing the refrigeration capacity and reducing the energy consumption of the existing refrigeration systems. Where applicable, major cost savings can be achieved by changing from timer-based defrost control scheme to the more energy efficient demand-based control. Another major control measure is to set the system head pressure based on the measured outdoor air wet-bulb temperature (a.k.a. floating head pressure control). System optimizations include subcooling in two-stage systems, reconfiguring condensers, and where possible increasing the suction pressure. The cost cutting measures listed in Tables 2 through 7 were all identified during the plant-wide assessments of the seven fruit and vegetable processors. The number in parenthesis indicates the number of times a measure was recommended in seven audits. No incentives were included in the economic payback analysis.

TABLE 2 - SUMMARY OF REFRIGERATION SYSTEM CONTROLS & OPTIMIZATION MEASURES

Energy Efficiency Measure (# times)	**Energy Savings** (kWh/yr)	**Demand Saving** (kW)	**Simple Payback Period** (years)
Demand-Based Defrost Control (5)	46,000 - 765,000	0	0 - 6.0
Floating Head Pressure Control (4)	100,000 - 1,200,000	16 - 319	0 - 0.8
Ammonia Subcooling (2)	230,000 - 585,000	27 - 67	1.0
Reconfigure Condensers (1)	265,000	287	0.6
Install an Intermediate Pressure Suction Line (1)	44,000	10	2.3
Increase Suction Pressure (1)	78,000	21	0
Improved Precooling of Blanched Vegetables (1)	156,000	65	0.8
Two-Stage Compression Instead of One (1)	410,000	62	0

Table 2 shows that refrigeration system controls and optimization related measures typically have high energy, demand, and cost savings. Moderate implementation costs result in an average simple payback period of less than a year.

Refrigeration Equipment Upgrades

Replacing existing refrigeration equipment can have the benefits of reduced energy consumption, improved reliability, and reduced maintenance costs. Each of the smaller processing plants had installed individual quick freezers (IQFs) fed by single-stage ammonia refrigeration system. Although lower at first cost, it was recommended to reconfigure these systems into two-stage systems with the addition of a second (or third) compressor, intercooler, and other equipment. A simple efficiency improvement involved increasing the insulation of pipes, tanks, and cold storage rooms and reducing the infiltration of warm air into refrigerated spaces. Increasing the evaporative condenser capacity and implementation of floating head control was recommended at three facilities. On two occasions, increasing the heat transfer area or changing the type of evaporators used in cold storage spaces improved their heat transfer rate, which allowed the refrigeration suction pressure in the low-temperature evaporators to be raised.

TABLE 3 - SUMMARY OF REFRIGERATION EQUIPMENT UPGRADE MEASURES			
Energy Efficiency Measure (# times)	**Energy Savings** (kWh/yr)	**Demand Saving** (kW)	**Simple Payback Period** (years)
Reconfigure Refrigeration System into a Two-Stage System (5)	125,000 - 380,000	28 - 153	1.9 - 5.0
Increasing Insulation & Reducing Infiltration (4)	9,000 - 98,000	0 - 11	0.2 - 5.1
Increasing the Evaporative Condenser Capacity (3)	215,000 - 309,000	25 - 58	0.8 - 1.3
Increasing Evaporator Heat Transfer Rate (2)	132,000 - 654,000	15 - 75	0.5 - 6.5

Table 3 shows that measures involving the upgrading of refrigeration equipment typically have high energy, demand, and cost savings. Relatively high implementation costs result in an average simple payback period of about two years.

High Efficiency Lighting & Controls

Although lighting is not a major cost for these facilities, opportunities were identified to reduce lighting energy usage by high efficiency lighting retrofits and lighting controls. Occupancy sensors, daylight sensors, and bi-level lighting controls on HID fixtures were typical recommendations at the audited plants. Installation of high efficiency T8 and T5 fluorescent fixtures, compact fluorescent lamps, and metal halide lighting were recommended where T12 fluorescent, incandescent, and halogen lighting was found.

TABLE 4 - SUMMARY OF HIGH EFFICIENCY LIGHTING & CONTROLS MEASURES			
Energy Efficiency Measure (# times)	**Energy Savings** (kWh/yr)	**Demand Saving** (kW)	**Simple Payback Period** (years)
Controlling Existing Lighting (7)	8,000 - 50,000	2 - 12	0.5 - 5.0
Install High Efficiency Lighting (5)	4,000 - 255,000	1 - 29	1.0 - 2.2

Table 4 shows that lighting related measures have low-moderate energy, demand, and cost savings. Relatively moderate implementation costs result in an average simple payback period of about two years.

Motor Drives & Controls

Opportunities to reduce the energy consumption of motors driving pumps, fans, blowers, hydraulic pumps, process machinery, and conveyors were identified at each of the audits. Application of variable frequency drives (VFDs) to control equipment serving a variable process load was recommended seven times. Using premium efficiency motors as standard efficiency motors burnout is recommended as a standard practice. In two cases, it was recommended to use VFDs to control the airflow of IQF blowers, which could result in substantial energy savings and increased productivity (reduction in product waste due to high air speed).

TABLE 5 - SUMMARY OF MOTOR DRIVES AND CONTROL MEASURES			
Energy Efficiency Measure (# times)	**Energy Savings** (kWh/yr)	**Demand Saving** (kW)	**Simple Payback Period** (years)
Controlling Motors with VFDs (7)	42,000 - 168,000	4 - 68	0.8 - 2.8
Install Premium Motors as Motors Burn Out (5)	20,000 - 127,000	2 - 20	0.7 - 1.6
Install Cogged-Type V-Belts (3)	29,000 - 102,000	4 - 13	0.3 - 0.8
On/Off Motor Control (2)	15,000 - 46,000	0 - 5	0 - 0.6

Table 5 shows that motor related measures typically have moderate energy, demand, and cost savings. Relatively low implementation costs result in an average simple payback period of less than a year.

Steam Boiler Systems

Opportunities to reduce the natural gas energy consumption of steam boilers were identified at many of the audits. Heat recovery from boiler stack economizers and installation of condensate return systems are significant opportunities for cutting the energy costs of a plant's steam system. Other measures such as tuning and adjusting the air-to-fuel ratio of the boilers, and automatic blowdown controls were also recommended.

TABLE 6 - SUMMARY OF STEAM BOILER SYSTEM MEASURES			
Energy Efficiency Measure (# times)	**Energy Savings** (therms/yr)	**Cost Saving** ($/yr)	**Simple Payback Period** (years)
Install a Condensate Return System (2)	9,000 - 17,000	4,000 - 14,000	2.0 - 2.7
Install Heat Recovery Economizer (2)	5,000 - 48,000	3,000 - 34,000	0.9 - 6.3
Tune and Adjust Air-to-Fuel Ratio (2)	5,000 - 15,000	3,000 - 11,000	0
Automatic Blowdown Controls (2)	3,000 - 13,000	3,000 - 9,000	1.3 - 1.9

Table 6 shows that boiler related measures typically have modest natural gas energy and cost savings. Relatively moderate implementation costs result in an average simple payback period of between one and two years.

Time-Of-Use Cost Savings Strategies

Opportunity to shift part or all of the cold storage refrigeration load out of the utility's summer "peak" demand period was identified at four of the audits. At two plants, this cost savings practice was already being implemented with much success. Load-shifting in frozen vegetable warehouses has been shown to save up to 56% of the total cooling costs without affecting food quality (Altwies, 1999).

TABLE 7 - SUMMARY OF TIME-OF-USE COST SAVINGS MEASURES			
Energy Efficiency Measure (# times)	**Peak Demand Savings** (kW)	**Cost Saving** ($/yr)	**Simple Payback Period** (years)
Shift Refrigeration Load (4)	155 - 600	11,000 - 31,000	0

Table 7 shows that refrigeration load shifting measures typically have significant demand and cost savings with little or no implementation cost.

The potential cost savings for energy efficiency measures was found to differ significantly between the large and small sized processing plants. Figures 4 and 5 illustrate which energy efficiency measure categories had the most impact on energy cost savings by typical plant size. The pie charts show energy cost savings for each measure category as a percentage of total energy cost savings for both small and large processing plants.

Figure 4. Percentage of Energy Cost Savings by Measure Category for Small Plants

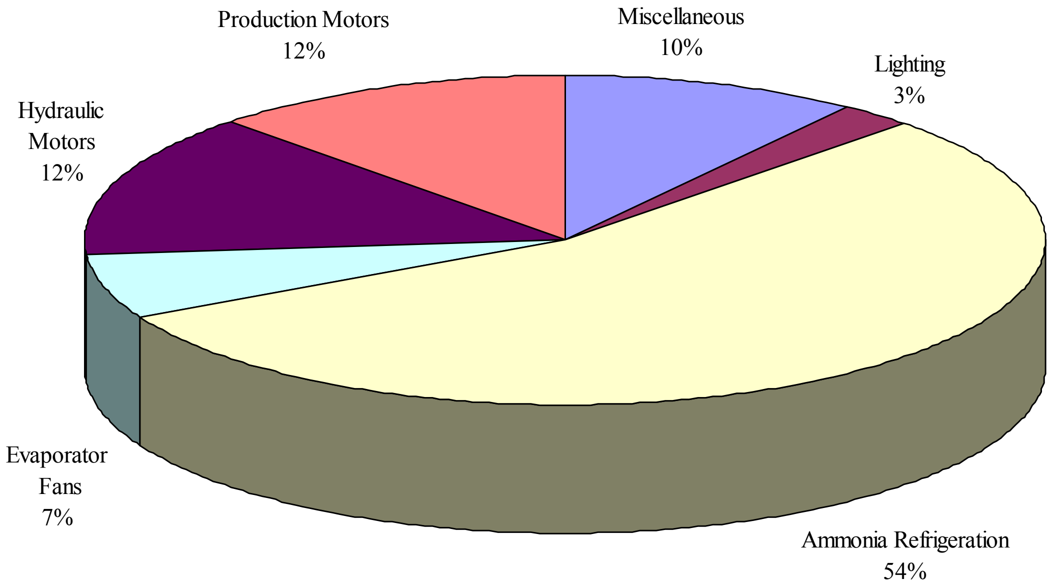


Figure 5. Percentage of Energy Cost Savings by Measure Category for Large Plants

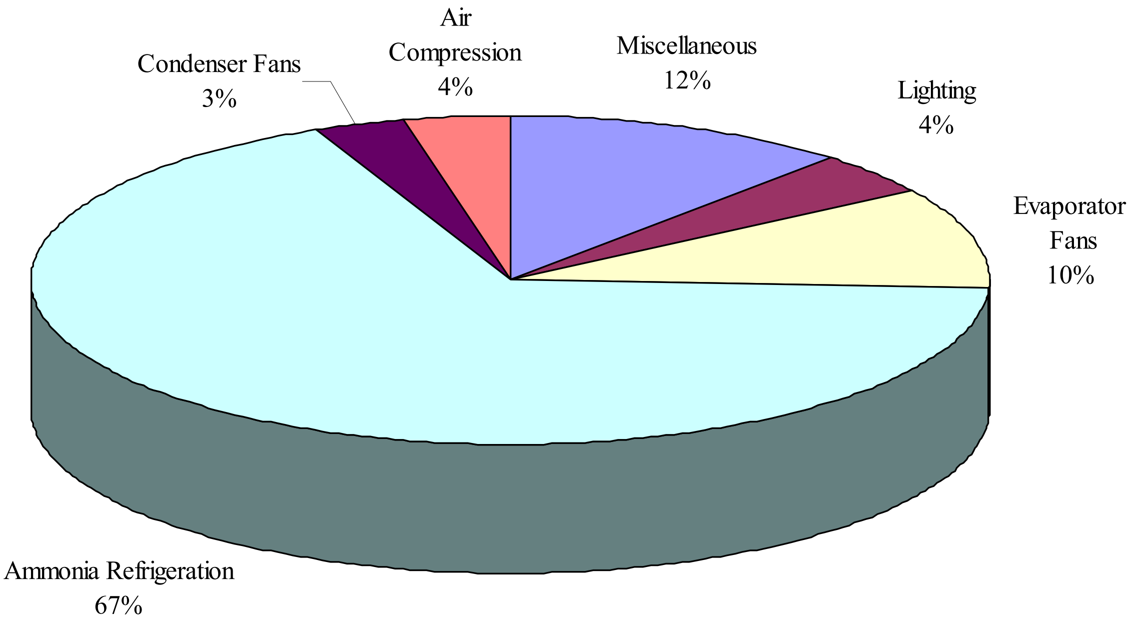


Figure 4 shows that there is significant potential for energy cost savings in both the installation of high efficiency refrigeration equipment and in the optimization & control of the existing refrigeration systems at the smaller plants. The older vintage of compressors and controls in the ammonia refrigeration systems at the smaller plants made them ideal candidates for energy cost savings in these two measure categories. Substantial cost savings can also be found in the installation of motor drives & controls as well as time-of-use shifting strategies for the cold storage refrigeration systems.

Figure 5 shows that there is significant potential for energy cost savings in the optimization & control of the existing refrigeration systems at the large plants. The larger plants already had newer, more efficient compressors and condensers, but lacked integrated controls to control and optimize their operation as production loads and outdoor climate conditions changed. Substantial cost savings can also be found in the installation of motor drives & controls as well as boiler system improvements.

Table 8 shows the percentage of a plant's energy cost that the energy efficiency assessments indicated could be realized by implementing measures in the listed categories. The data shows that while both large and small size plants benefit from improving their refrigeration system control and optimization, only the small plants had significant potential cost savings in all of the measure categories. Overall, the small sized plants have greater opportunity for reducing their electrical cost than do the large sized plants (16.1% vs. 7.5%) as well as greater opportunity for reducing their natural gas cost than do the large sized plants (12.2% vs. 5.0%).

TABLE 8 - SUMMARY OF PERCENT ENERGY COST SAVINGS[*] BY PLANT SIZE		
Measure Category	**Cost Savings as a Percentage of Energy Cost**	
	Large Plant	**Small Plant**
Refrigeration Control & Optimization	5.3%	5.5%
Refrigeration High Efficiency Equipment	0.5%	6.4%
Lighting	0.3%	1.0%
Motor Drives & Controls	1.2%	1.6%
Boiler Systems	5.0%	12.2%
Time-Of-Use Shifts	0.2%	1.6%

[*] Cost savings is for energy source of related measure. Hence, the boiler related measures show the percentage cost savings of the plant's annual natural gas cost.

Conclusion

The results from detailed plant-wide energy audits of seven processing plants in California were described and potential savings for small and large size processing plants were addressed. Significant opportunities for energy efficiency exist both in larger and smaller plants, especially in their refrigeration systems. Considering the small number of samples for smaller and larger size plants, the larger size plants benefit significantly more from refrigeration system control and optimization while the smaller size plants were found to benefit in both categories of high efficiency refrigeration equipment and refrigeration system control and optimization. Other cost savings opportunities exist in lighting, boiler systems, motor drives and control, and time-of-use refrigeration load-shifting.

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