REDUCING ENERGY COSTS IN FRUIT STORAGE WAREHOUSES[1]

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INTRODUCTION

Fruit storage capacity continues to increase in the Pacific Northwest states, primarily in Washington. Information provided by the U.S. Department of Agriculture's National Agricultural Statistical Service (NASS) lists regular atmosphere plus controlled atmosphere apple and pear storage capacity in Washington as approximately 8,108,000 bins and Oregon capacity as approximately 524,000 bins in 1999. Implementation of energy saving management strategies continues to be emphasized throughout the region. This report documents energy savings realized and in-room atmosphere changes initiated as a consequence of two energy saving management options.

PROCEDURES

Two previously instrumented rooms located at Duckwall-Pooley Fruit Company's Odell site were used for the 2000 - 2001 storage season study. Room CA 16 (28 feet wide by 61 feet long and 28 feet high) was filled as a conventionally stacked room with 769 wooden bins and 115 plastic bins of field-run D'Anjou pears. The wooden bins were stacked 11-high and pallets with hydrated lime were placed on the top bins to control carbon dioxide evolution. Based on the formula 24 boxes of pears per wooden bin x 44 pounds per box, CA 16 held approximately 946,000 pounds of fruit. Room CA 13 (30 feet wide by 61 feet long and 28 feet high) was filled as a tight-stacked room with 964 plastic bins of field-run D'Anjou pears. Bins were stacked 10-high and pallets of hydrated lime were placed on the top bins. Room CA 13 held approximately 1,120,000 pounds of fruit. Plastic bins were assumed to hold 10% more fruit than wooden bins.

Each room is equipped with one Krack evaporator unit. Each unit has four 30-inch diameter fans each powered by a 2-HP fan motor. The evaporator units have four fins per inch, a rated cooling capacity of 23.0 tons of refrigeration and total air circulation of 50,700 cfm. As fruit bins were placed in each room, thermistors were placed among the fruit in Bins 1 (on the floor), Bins 6 (six bins above floor level) and Bins 10 or 11 (the top bin) at nine locations. Fruit temperature measurements were taken at these 27 locations throughout the study at 10-minute intervals. Additional data recorded included dew point temperature at one location, refrigerant temperature into and out of the evaporator coil and air temperatures at three locations; as air entered the rear of the evaporator coil, approximately 1 foot in front of the coil and at mid-room at the same elevation as the evaporator coil. Fruit mass loss was measured two ways in each room. Prior to room closure, 50 fruit were randomly selected from bins being placed in each room. Each fruit was numbered and weighed. The 50 fruit were then placed on the load-cell mass loss instrument and continuous measurement of mass was initiated. Data were recorded at 5-minute intervals

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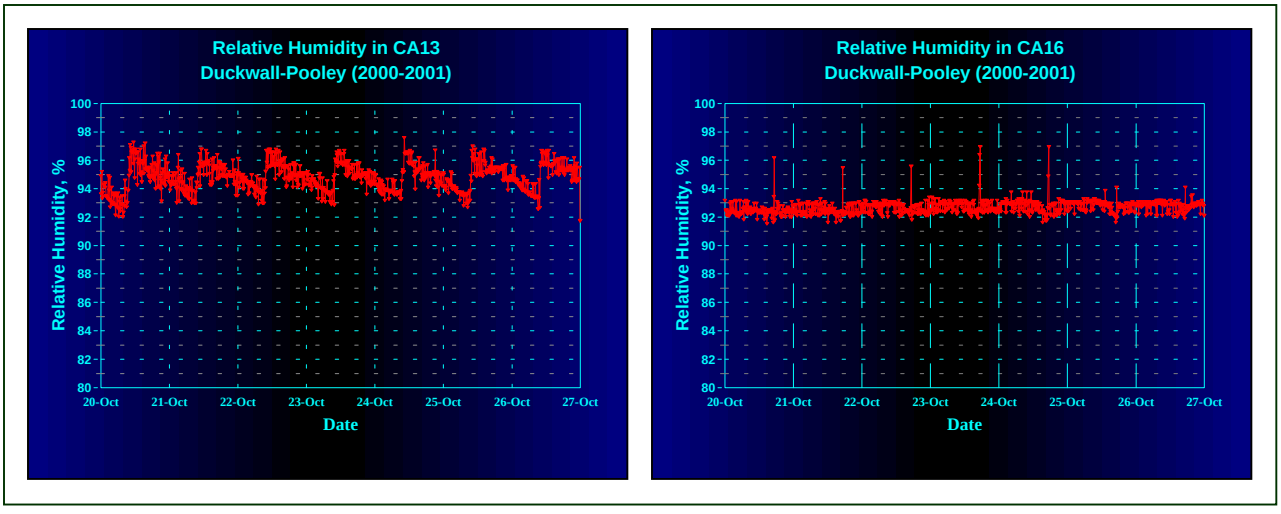
throughout the study. At the conclusion of the storage period, each fruit was reweighed and mass loss was compared to the load-cell data. Hellickson and Baskins (1996) presented a complete description of fruit temperature measurement locations. Evaporator fan and compressor energy use were measured and recorded at 10-minute intervals. Room oxygen and carbon dioxide levels were measured and recorded at 10-minute intervals.

Three modes of room operation were evaluated. Mode 1 was normal room management with all four evaporator fans operating full-time and room set point temperature at 30 ºF. Mode 2 was to simply turn off two of the evaporator fans. Mode 3 was to continue using only two evaporator fans and to then fan cycle on a 2 hours on/2 hours off schedule. The room set point temperature was lowered 0.3 ºF during the Mode 3 operating period. One defrost period was scheduled per day in each room.

RESULTS AND DISCUSSION

Refrigerant temperature was nearly identical in each room prior to starting Mode 2 operation. When two of the fans were turned off, airflow through the coil was reduced to one-half and the refrigerant temperature immediately declined to maintain the 30 ºF room set point temperature. Refrigerant temperature regained a stable value in room CA 16; while a cyclic pattern developed between defrost events in room CA 13. Immediately after defrost, the refrigerant temperature in CA 13 was essentially the same as when four fans were operating. A nearly linear decline of about 1.5 ºF was then recorded until the next defrost event. This pattern is consistent with excess ice accumulation on the evaporator coil thereby additionally reducing airflow within the room. The air temperature difference or "split" across the coil increased from about 0.25 ºF to approximately 0.5 ºF in both rooms. Differences in ammonia temperatures in each room during two fan operation was the result of approximately 174,000 pounds more pears in room CA 13. The excess moisture load from this fruit was sufficient to cause the evaporator coil in CA 13 to accumulate ice more rapidly than in room CA 16.

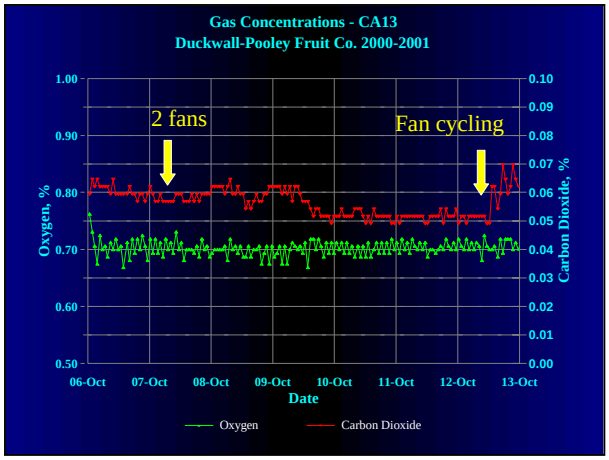
Because refrigerant temperature in CA 13 was cyclic, so was room relative humidity. This cyclic pattern ranged between 96% and 93% closely following the refrigerant temperature changes. Relative humidity in CA 16 was essentially unaffected, at approximately 93%. Room CA 13 consistently remained 3 to 5% higher in relative humidity than CA 16 throughout each study period.

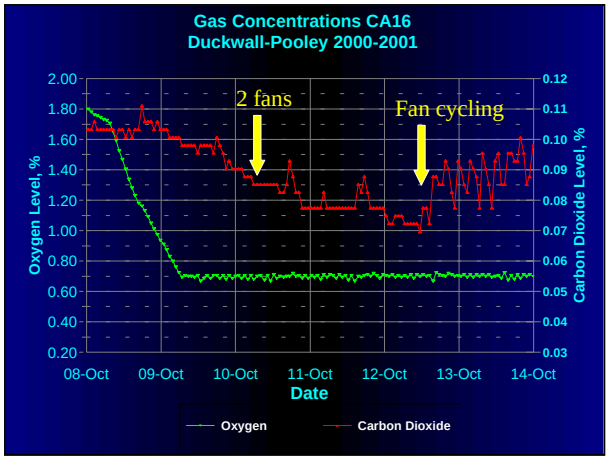


Mode 3 operation induced a 1.5 ºF drop in ammonia temperature during the fan on periods, which included intentionally lowering the room set point 0.3 ºF. During the fan cycling period, room relative humidity ranged from 96% to 92% in CA 13 and from 92% to 89% in CA 16. The high values were recorded during fan off periods.

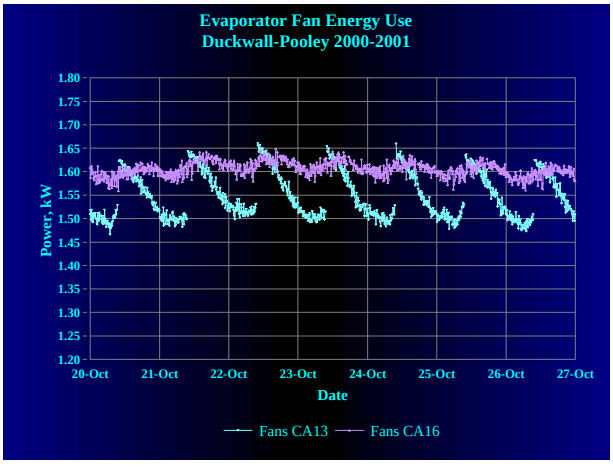
Fruit mass loss was measured until each room was opened for fruit presizing. Fruit mass loss in CA 13 was 1.04% during 47 days in storage and fruit in CA 16 lost 0.96% in 41 days. Once stable room conditions were achieved, the slope of the mass loss values continued to become slightly less each week. However, fruit mass loss in CA 16 remained slightly steeper than in CA 13 during each weekly comparison period. Thus, the fruit in CA 16 lost mass at a slightly greater rate than the fruit in CA 13.

The gas levels in the two study rooms were stable at approximately 0.7% O_2 and 0.06% CO_2 during full fan operation. Turning off two fans in each room did not adversely affect gas levels. Fan cycling 2 hours on/2 hours off caused CO_2 to increase 0.02% in each room. After the initial increase, CO_2 levels stabilized and cycled between 0.06% and 0.08%. Increased CO_2 levels occurred during the periods the fans were off as no forced air movement past the lime was present.





Evaporator fan energy use for four 2-HP fans running continuously, except for defrost events was approximately 1000 kWh/week. During Mode 2 and Mode 3 operation, recorded values were about 500 kWh/week and 260 kWh/week, respectively. Ice accumulation on the evaporator coil in CA 13 also caused a cyclic pattern of fan motor energy use in that room.



Fruit temperatures measured at 27 locations in each room were stable during Mode 1 operation. Fruit temperature in the bin on the floor farthest from the evaporator coil in

CA 13 gradually increased 0.5 ºF when two fans were turned off. All other locations monitored remained stable or decreased in temperature. Fruit temperatures in bins on the floor in both rooms (two locations in CA 13 and one in CA 16) increased 0.5 ºF then stabilized during fan cycling.

Tables 1 through 3 summarize the consequences of operating the evaporator fans in each of the three modes.

Table 1. Operation Mode 1 - Four Evaporator Fans on Continuously.

	Room CA 13	**Room CA 16**
Amount of Fruit in Room	1,120,000 lbs	946,000 lbs
Ammonia Temperature	Stable @ 26.75 ºF	Stable @ 26.75 ºF
Air Temperature Entering Evap. Coil	29.75 ºF	29.7 ºF
Air Temperature Split across Coil	0.25 ºF	0.20 ºF to 0.25 ºF
Relative Humidity	95% to 96%	91.5% to 92%
Fruit Temperature	Stable	Stable
Slope of Fruit Mass Loss	Linear	Linear > CA13
Evaporator Fan Energy Use	974 kWh/week	993 kWh/wk

Table 2. Operation Mode 2 - Two Evaporator Fans on Continuously.

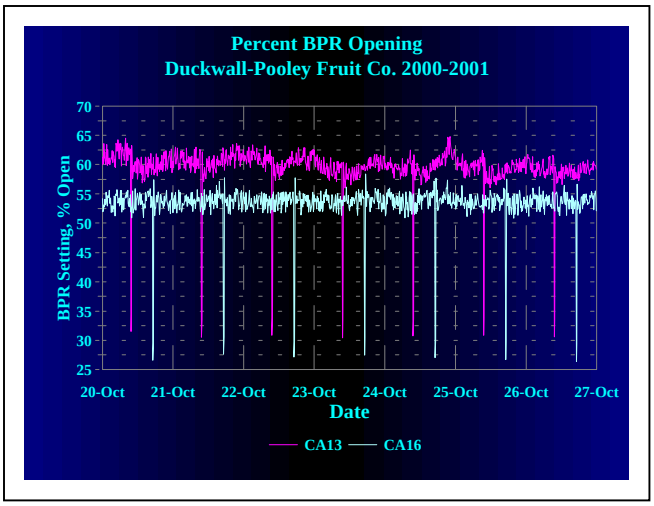
	Room CA 13	**Room CA 16**
Amount of Fruit in Room	1,120,000 lbs	946,000 lbs
Ammonia Temperature	Cyclic 27 ºF to 25.5 ºF	Stable @ 26.5 ºF
Air Temperature Entering Evap. Coil	Cyclic 30.2 ºF to 29.8 ºF	30.0 ºF
Air Temperature Split across Coil	Cyclic 0.8 ºF	0.75 ºF
Relative Humidity	Cyclic 97% to 92%	91.5% to 92%
Fruit Temperature	1 bin on floor ^ 0.5 ºF	Stable
Slope of Fruit Mass Loss	Linear	Linear > CA 13
Evaporator Fan Energy Use	501 kWh/wk	520 kWh/wk

Table 3. Operation Mode 3 - Two Evaporator Fans Cycled 2 Hours On/2 Hours Off.

	Room CA 13	**Room CA 16**
Amount of Fruit in Room	1,120,000 lbs	946,000 lbs
Ammonia Temperature	24 ºF to 26 ºF	23.5 ºF to 26 ºF
Air Temperature Entering Evap. Coil	30.0 ºF to 29.75 ºF	29.7 ºF
Air Temperature Split across Coil	1.0 ºF	1.25 ºF
Relative Humidity	97% to 92%	92% to 88%
Fruit Temperature	2 bins on floor ^ 0.5 ºF	1 bin on floor ^ 0.5 ºF
Slope of Fruit Mass Loss	Linear	Linear > CA 13
Evaporator Fan Energy Use	264 kWh/wk	260 kWh/wk

CONCLUSIONS

Ammonia temperature is the primary controller of room air and fruit temperatures, relative humidity, mass loss and eventually fruit quality. Turning off one-half of the evaporator fans caused the three sensors that control BPR opening (located at the opposite end of the room from the evaporator coil) to sense a slightly higher average temperature. This increased refrigerant flow through the coil thereby causing it to operate at a lower temperature. Turning off one-half of the evaporator fans also caused less coil surface area to be actively used to cool returning air. Portions not being swept by the return air appeared to accumulate ice more rapidly than during full fan operation. Because room CA 13 contained approximately 174,000 pounds more pears than CA 16, the daily defrost event in CA 13 was not frequent enough to prevent partial airflow stagnation at the coil. As ice continued to accumulate on the evaporator coil in CA 13, the BPR continued to slowly open to counteract the reduced cooling. The combination of excess ice and reducing ammonia temperature in the coil caused the cyclic conditions recorded. These conditions were not recorded in CA 16 and the daily defrost event was sufficient to control ice removal from the evaporator coil in that room.



Although refrigerant and air temperatures and relative humidity in CA 13 became cyclic during Mode 2 operation, fruit temperatures were stable and mass loss was less in CA 13 than in CA 16.

Room CO_2 levels fluctuated during fan cycling because lime stacked on the top layer of bins was used for control. Rooms that use active CO_2 scrubbing should not experience this range of fluctuation during fan cycling.

Although fruit temperature increases were recorded in bins on the floor during Mode 2 and Mode 3 operation, once the initial increase of 0.5 ºF was realized, each temperature curve then leveled off. This slight increase in fruit temperature at three locations (two in CA 13 and one in CA 16) is not considered sufficient to negate the energy saving effects of fan cycling. More frequent defrosting of the evaporator coil in CA 13 would likely reduce or eliminate the recorded fruit temperature increase in that room. Improved air distribution within each room would also be beneficial.

REFERENCES

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