FINAL REPORT
WTFRC Project # PH-03-892 **Organization Project #** ORE00463

Project Title: Improving Air Distribution in Fruit Storage Warehouses

PI: Martin L. Hellickson, Ph. D., P.E., Retired
Organization: Bioengineering Department
Oregon State University
Corvallis, OR 97331

Cooperators: Regional Fruit Storage Warehouses

Objectives:

1. Document precise room interior dimensions, equipment and capacities in regional storages.
2. Document actual fruit bin stacking patterns in regional CA fruit storage rooms.
3. Document evaporator unit locations, sizes and capacities in typical CA storage rooms.

Significant Findings:

- **Air Circulation Capacities**. In-room air circulation capacity varied from a low value of 25.00 cfm/bin in a 1000 bin room to a high of 61.45 cfm/bin in a 825 bin room. Evaporator fan capacities between 42.63 and 47.93 cfm/bin were frequently found in rooms built in 1990 and later. One regional refrigeration and control systems company currently recommends 45 cfm/bin.

- **Room Configurations**. Room dimensions were determined as width being the measurement perpendicular to evaporator fan air flow and depth being the same direction as fan air flow. Although a myriad of room sizes exist, the widest measured was 100 feet wide by 42 feet deep. The deepest room measured was 28 feet wide by 100 feet deep. Excessively deep rooms cause significantly reduced air flow at the wall opposite the evaporator unit(s).

- **Door Sizes and Locations**. All the rooms observed had one entrance/exit door. Measured door opening widths were 9’-6”, 9’-0”, 8’-11”, and 8’-6”. Door locations varied from being centered on the interior floor area to being very close to a sidewall. Door location significantly affects forklift movement during final stages of room filling. Door opening heights typically limit bin stacking height to 5 bins directly in front of the door.

- **Bin Placement and Stacking Procedures**. Storages that use plastic bins typically tight-stack all bins and reduce the airspace between bins and sidewalls as compared to using wooden bins. Plastic bins eliminate the need to cross stack bins to accommodate forklift movement, thus can maintain runner space alignment throughout the entire room depth. Rooms filled with wooden bins with one-way pallets require some locations to be cross-stacked to accommodate forklift movement.

- **Bin Placement Near Doors.** Bin placement near the entrance/exit door was frequently modified to facilitate forklift egress without damaging the side of the opening. Many operators will leave spaces so that final stacks of bins are placed at an angle to the long axis of the room. Unwanted spaces also occurred when the first bins placed in a room were not properly located. These instances created large empty spaces from the floor upward that had a profound adverse effect on airflow uniformity.

- **Uniformly Placed Plastic Bins.** Creating a symmetrical stacking pattern in a 1000 bin room filled with tight-stacked plastic bins created the most uniform air flow patterns, as documented by Hellickson and Baskins, 2003. Careful placement of bin stacks near the door by forklift operators was required to achieve this result. The use of plastic bins made precise stacking of the bins possible, as sometimes an entire 9 or 10 bin stack was moved a few inches sideways to fit properly.

Methods:

This report was developed from visits to several fruit storage facilities located in Oregon and Washington. All rooms were designed to maintain controlled atmosphere conditions. Specific data recorded included room inside dimensions of floor space, door size and location, plus number, size, location, capacity and manufacturer of evaporator units present in the room. Data were gathered during periods that rooms were empty and when filled. Designated bin placement schemes and actual bin stacking patterns present at room closing were also documented. Empty room visits facilitated obtaining precise special measurements and reported capacity data. Follow-up visits to several locations were made when rooms are either being filled or after rooms had been filled to verify actual bin counts and stacking patterns.

Discussion:

Table 1 illustrates examples of detailed information obtained for evaporator units present in various CA rooms. Evaporator unit manufacturers included Colmac, Krack, McCormack, Recold, and Frigid Coil. Company representatives were contacted to obtain complete nomenclature explanations for each model identified in various storage facilities. Many installations include modifications to standard evaporator units to meet specific room needs. Thus, precise size and performance data must be obtained from building plans or similar documentation. After installation modifications such as resizing fan motors will also affect actual system capacity and performance. Each coil manufacturer has their unique nomenclature to identify specific configurations. For example, Colmac coils observed had nomenclature identification beginning with APC, APC100, ALP or ALPX depending on physical dimensions and fan motor diameter and horsepower. Later models from the same company may be identified by the ICH group (**I**ndustrial **C**oolers, **H**igh profile) they are rated within. Krack coils observed in the region were identified as DT (draw through), BT (blow through). Older units included identifiers as WD (water defrost) and APPL. McCormack coils had designators of 7VHL, 7VHE, 3PCH, 6PCH, 7AAH and 7VHG. Subsequent numbers and letters in the nomenclature for specific coils typically referred to the number of rows deep of cooling tubes that were present, fins per inch, hot gas or water defrost, flooded coil, ammonia refrigerant, fan diameter, number of fans and tons of refrigeration capacity at 12 ^{o}F temperature difference across the coil.

Room configuration and general bin stacking information was obtained for 353 CA rooms operated by 12 different storage organizations (Table 2). Some facilities included information on bin capacities depending upon whether apples or pears were to be stored in the room, bin stacking heights, use of wooden or plastic bins, door size and locations, evaporator unit location, and in some rooms, where cross-stacking of wooden bins took place to accommodate forklift movement. Several rooms were viewed during the past three storage seasons to document actual bin placement as compared to generally identified stacking pattern. Several rooms had actual bin placement that was markedly different than the listed placement plan. This information was used to construct two-dimensional schematics of the rooms and occupying fruit. Figures 1 and 2 illustrate idealized and actual bin placement patterns, which changes the same room from a conventionally stacked room holding a listed 910 bins to a tight-stacked room holding 1170 bins. On-sight verification found that neither of the bin counts listed for this room were exact. Figure 3 illustrates this typical finding for a specific room. Bin height is also identified to verify actual bin count. Spaces left for forklift movement and in front of the door often reduced the actual count. Additionally, errors made by forklift drivers in placement of the first row of bins in two rooms surveyed created open spaces in later rows and an unbalanced room (non-uniform placement of bins within the rectangular floor space). This nonsymmetrical placement of fruit bins was shown to adversely affect fruit cool down in the room by requiring longer than normal to achieve the room set point temperature.

Hellickson and Baskins (1996, 1997, 2000 and 2003) have presented research findings that addresses some of the potential causes of fruit quality losses experienced during storage. The first two studies documented differences in fruit cool down rates at various locations within two 1000-bin storerooms. Results of studies documenting differences in airflow patterns in a 1000 bin storeroom due to varying bin-stacking patterns were reported at the 8th International Controlled Atmosphere Research Conference held in Rotterdam, The Netherlands. Bin placement within the room is critical to achieving uniform air distribution and uniform fruit cool down. Cross stacking wooden bins (required for forklift movement) and either leaving empty spaces or creating extra spaces by turning bin stacks to allow forklifts to exit the room more easily causes significant changes in airflow patterns. Plastic bins eliminate cross-stacking problems. However, elimination of excess space necessitated for forklift movement must still be achieved.

Information assembled on room bin and evaporator unit capacities in various storages indicates that the amount of airflow per bin of fruit varies widely. The lowest value documented was 25.00 cfm per bin in a 1000 bin room. The highest value found was 61.45 cfm/bin in a 825 bin room. Evaporator fan capacities between 42.63 and 47.93 cfm/bin were more frequently found in facilities built in 1990 and later. Providing sufficient airflow to attain uniform cooling and long term uniformity of fruit temperature throughout the storeroom is critical to retention of fruit quality. Excessive airflow tends to increase fruit mass loss (water loss) and wastes electrical energy used by both fan motors and by compressor motors which must increase run time to meet a higher cooling load.

Research has shown that uniformity of air distribution within each fruit storage room is profoundly affected by bin placement and stacking patterns. Hellickson and Baskins (2003) documented differences in air movement in a 1000 bin room equipped with one evaporator unit that provided air movement with four 30-inch diameter fans. Empty spaces and non-symmetrical bin placement caused major changes in airflow patterns.

Achieving the overall objective of providing the highest possible quality fruit to consumers requires careful attention to each phase of production, storage, transportation and distribution. One breakdown in this sequence can adversely impact product quality and profit. Establishment and maintenance of proper storage conditions is a vital link in this chain of events. Minimal differences in room temperature, relative humidity, gas content and uniformity of air distribution can cause significant quality and quantity losses. The longer fruit are stored, e.g. long-term controlled atmosphere storage, the greater the adverse impact these differences can become.

Room Sizes and Capacities

Room sizes in regional storage facilities vary greatly in both width and depth. (In this document, depth is measured in the same direction as air flow from an evaporator unit. Maximum and minimum room depths documented were 100 feet and 28 feet, respectively. Maximum and minimum room widths documented were 100 feet and 22 feet, respectively.

Room capacities listed by various storages ranged from the largest having an average bin count of 5000 and the smallest 810. Typically, these approximate capacities were reported for fruit stored in wooden bins that were spaced four to six inches between rows. Bin rows are defined as running perpendicular to room width. Some facilities differentiated room capacity depending upon whether apples or pears were to be stored.

Evaporator Manufacturers, Capacities and Locations

Evaporator units manufactured by the following companies were present in regional storerooms: Colmac, Frigid Coil, IMECO, Krack, Lewis, McCormack, Recold, and Wescold. Fan sizes varied from 18 inches to 42 inches in diameter. Fan motor horsepower varied from ½ HP to 5 HP. Cooling capacities ranged from 6.1 tons of refrigeration per unit to 58 tons. These capacities were typically determined based on a 12 ^{o}F temperature difference across the cooling coil.

Air movement capacity (cfm) of evaporator fans is affected by blade diameter and configuration, motor speed (rpm), motor horsepower, number of fin rows present, space between fins (fpi) and air density. Manufacturer reported values are typically for 32 ^{o}F air temperature and zero static pressure.

Bin Placement in Rooms

Airflow from the evaporator units into the storage space creates the cooling environment necessary to maintain fruit quality. The more uniformly this cooled air is circulated over, under and through the stacked bins, the better. As in any fluid-flow system, more air will flow in areas that create less resistance. Areas of greater flow resistance will receive less airflow. Research presented by Hellickson and Baskins (2000) documented real-time measurement of fruit cooling rates and efficiencies at 27 locations within regular-stacked and tight-stacked rooms filled with both wooden and plastic bins. Further research (Hellickson and Baskins, 2003) reported on how bin stacking patterns and open spaces left to allow egress of forklifts affected airflow in the same rooms.

Unless wooden bins have two-way pallets, space required for forklift movement dictates that some bins must be cross-stacked. Cross-stacked bins are those that the pallet runner space is perpendicular to the majority of bins in a row of bins. Regional warehouses have developed various stacking plans for wooden bins. Some line up all runner spaces from the rear of the room to near the exit. Then two or three rows of bin stacks are rotated 90 degrees and spaced approximately one foot from the previous stacks. As the stacking space directly in front of the exit door is filled, bin stacks are frequently angled such that the forklift can exit the room without damaging the door casing. Plastic bins are manufactured with two-way pallets which eliminates cross-stacking.

Tight-stacking bins

Conventional stacking of fruit bins attempts to maintain an open space of approximately six inches between rows to facilitate airflow past the containers and thereby improve fruit cooling. Maintaining this space between rows of wooden bins is seldom accomplished due to wood deflection. Additionally, most wooden bins do not have ventilation slots in their vertical sides. Therefore, the amount of heat transferred from the fruit through the solid sides of a bin is minor compared to cooling induced by air passing through the runner space.

Research presented by Hellickson and Baskins (2000) showed that equal cooling rates were achieved when fruit were tight-stacked. Tight-stacking bins eliminates space between rows of bins and results in increased airflow through runner spaces where the majority of fruit cooling is accomplished. Additionally, tight-stacking a room may allow additional fruit to be stored in the same space.

Recommendations:

- **Bin Placement and Stacking Procedures**. Storages that use plastic bins should tight-stack all bins and reduce the airspace between bins and sidewalls to 6" to 9. Minimum spacing between bins and the back wall should be 24". Approximately the same space should be maintained between the wall underneath the evaporator units and bin stacks.

  Rooms filled with wooden bins should only cross-stack the bins that the forks actually contact. The other bins in these stacks should be oriented as to maintain runner space continuity as much as possible. Minimum spacing between bins and the back wall should be 24". Approximately the same space should be maintained between the wall underneath the evaporator units and bin stacks.

- **Increasing Capacity by Tight-stacking.** The following calculators can be used to determine if a room can be tight stacked.

  For 48" x 48" wooden bins the number of bins wide (N) will be:

  1. **Conventional Stack –** N = (Room width in feet -1.5 feet) /4.5 feet
  2. **Tight Stacked -** N = (Room width in feet – 1 foot)/4 feet

  For Model 28 – 48.87" x 48.87" plastic bins the number of bins wide (N) will be:

  3. **Conventional Stack -** N = (Room width in feet -1.5 feet) /4.5725 feet
  4. **Tight Stacked -** N = (Room width in feet – 1 foot)/4.0725 feet

  For conventional stacked bins, 12" space at each sidewall is assumed.
  For tight-stacked bins, 6" space at each sidewall is assumed.

- **Evaporator Capacity and Tight-Stacking**. Operators should determine if sufficient evaporator coil circulation capacity exists to accommodate the additional bins to be placed in a room. Reducing the airflow to less than 40 cfm/bin should be evaluated and may result in delayed cool down rates and unsatisfactory air distribution.

Budget:

Project Title: Improving Air Distribution in Fruit Storage Warehouses

PI: Martin L. Hellickson, Ph. D., P.E., Retired

Project Duration: 2003 - 2005

Current Year: 2005

Project Total: $7500
Current Request: $4000

Year	Year 1 (2003-2004)	Year 2 (2004-2005)
Total	$3500	$4000

Current Year Breakdown

Item		
Supplies	500	500
Publication costs	0	500
Travel	3000	3000
Total	3500	4000

References:

Hellickson, M. L. and R. Baskins. 1996. Cool-down comparisons of d'Anjou pears tight-stack versus conventional stacking. Or. AES Tech. Paper No. 10,956. Proceedings of the 12th Annual Washington Tree Fruit Postharvest Conference. Wash. State Hort. Assn. P.O. Box 136, Wenatchee, WA. 98807. March.

Hellickson, M. L. and R. A. Baskins. 1997. Effect of tight-stacking bins on fruit temperature reduction. Or. AES Tech. Paper No. 11,192. CA '97 Proceedings Vol. 1, Seventh International Controlled Atmosphere Research Conference, University of California, Davis, CA. July 13-18, 1997. (1): 64-69.

Hellickson, M. L. and R. A. Baskins. 2000. Pear Cool-down and Mass Loss, Comparing Plastic and Wooden Bins. Or. AES Tech. Paper No. 11,678. Proceedings of the 16th Annual Washington Tree Fruit Postharvest Conference. Wash. State Horticultural Association. P.O. Box 136, Wenatchee, WA. 98807. March.

Hellickson, M. L. and R. A. Baskins 2003. Visualization of airflow patterns in a controlled atmosphere storage. Or. AES Tech. Paper No. 11788. Acta Horticulturae No. 600. Proceedings of the Eighth International Controlled Atmosphere Research Conference, Rotterdam, The Netherlands. Vol. 1 (173-179). March.

Room	Make	Model	# Motors	HP	Capacity Per unit	Fins/in	Fan Dia	cfm / fan	Total cfm
CA	Frigid Coil	FALT-W-7500-P4	4	½	7.5 tons	4	18 in	3,600	14,400
CA	Recold	3500 FWA	5	½	10.8 tons	4	18 in	4,235	21,175
CA	Krack	WD6-10635 FLA	6	½	12.76 tons	4	22 in	4,000	24,000
CA	Krack	WD5 - 8575	5	½	10.30 tons	3	22 in	4,500	22,500
CA	Krack	APPL423LLP FLA	4	2	23 tons	4	30 in	12,675	50,700
CA	Krack	APPL431LLP FLA	4	3	31 tons	4	30 in	14,000	56,000
CA	McCormack	7AAHD44XLWFA00	5	1.5	33 tons	4	26 in	13,500	67,500
CA	McCormack	7AAHD44LWFA00	4	1.5	27.1 tons	4	26 in	13,750	55,000
CA	McCormack	4PCH060F63.5WFA00	4	3	31.3 tons	3.5	36 in	15,000	60,000
CA	McCormack	5PCH068E63.5WFA00	5	3	35.5 tons	3.5	36 in	13,600	68,000
CA	Colmac	APC-434-FL-L/R-W-460	3	2	20.4 tons	3	36 in	14,580	43,740
CA	Colmac	APC113-454-FL-L/R-W-460	5	2	41 tons	4	36 in	17,300	86,500

Table 1. Examples of Detailed Evaporator Unit Information.

Room	Year Built	Dimensions L X W X H	Floor Sq. Ft.	Rm Vol. Cu. Ft.	Capacity Normal Bins	Capacity Tight-Stack Bins
CA	1974	55 x 33 x 25	1815	45375	862	862
CA	1974	55 x 28 x 25	1540	38500	734	734
CA	1976	74 x 57 x 25	4218	105450	1988	2108
CA	1976	74 x 57 x 25	4218	105450	1988	2114
CA	1976	74 x 52 x 25	3848	96200	1821	1943
CA	1981	64 x 88 x 25	5632	140800	2774	3018
CA	1984	61 x 42 x 25	2562	64050	1245	1477
CA	1987	61 x 29 x 25	1769	44225	825	1012
CA	1990	61 x 33 x 25	2013	50325	965	1174
CA	1990	61 x 28.5 x 25	1739	43463	825	1012

Table 2. Examples of Detailed Room Information.

Name of Storage Company:		Contact Person:	
Address:		Phone:	Email:

Machine Rm: #1	Manuf.	Model #	Motor HP	Type	Capacity	Refrig.	BAC Evap Condenser 20 HP Axial Fan Motor 610 GPM Water Flow 446 TR @ 95°F Condenser Temp (68°F t_{wb}) 10 HP Condenser Pump
Compressor:	Vilter	448	100 HP	Recip. 4 cy	90 TR	NH_3	
Compressor:	Vilter	444	50 HP	Recip. 4 cy	45 TR	NH_3	
Compressor:	Sullair	C20 LA	350 HP	Screw	290 TR	NH_3	

Room	Coil Manufac	Model	# Evaps	# Fans per coil	Motor HP	Fins/In	Cooling Capacity	Cfm/fan	Total Fan CFM
CA	Krack	BTX6A-1620-FLA-WD	1	6	½	3	16 TR	5,400	32,400
CA	Krack	BTX5A-1300-FLA-WD	2	5	½	3	24 TR	5,400	54,000
CA	Krack	BTX5A-1300-FLA-WD	2	5	½	3	24 TR	5,400	54,000
CA	Krack	BTX5A-1300-FLA-WD	2	5	½	3	24 TR	5,400	54,000
CA	Krack	BTX6A-1620-FLA-WD	2	6	½	3	33 TR	5,400	64,800
CA	Krack	BTX5A-1300-FLA-WD	3	5	½	3	40 TR	5,400	81,000
CA	Krack	BTX6A-1620-FLA-WD	2	6	½	3	33 TR	5,400	64,800
CA	Krack	BTX6A-1620-FLA-WD	2	6	½	3	33 TR	5,400	64,800
CA	Krack	BTX5A-1300-FLA-WD	2	5	½	3	24 TR	5,400	54,000
CA	Krack	BTX5A-1300-FLA-WD	2	5	½	3	24 TR	5,400	54,000
CA	Krack	BTX5A-1300-FLA-WD	2	5	½	3	24 TR	5,400	54,000
CA	Krack	BTX6A-1620-FLA-WD	1	6	½	3	16 TR	5,400	32,400
CA	Krack	BTX6A-1620-FLA-WD	1	6	½	3	16 TR	5,400	32,400

Table 3. Examples of Detailed Machine Room and CA Storage Room Information.

Figure 1. Conventionally Stacked Room.

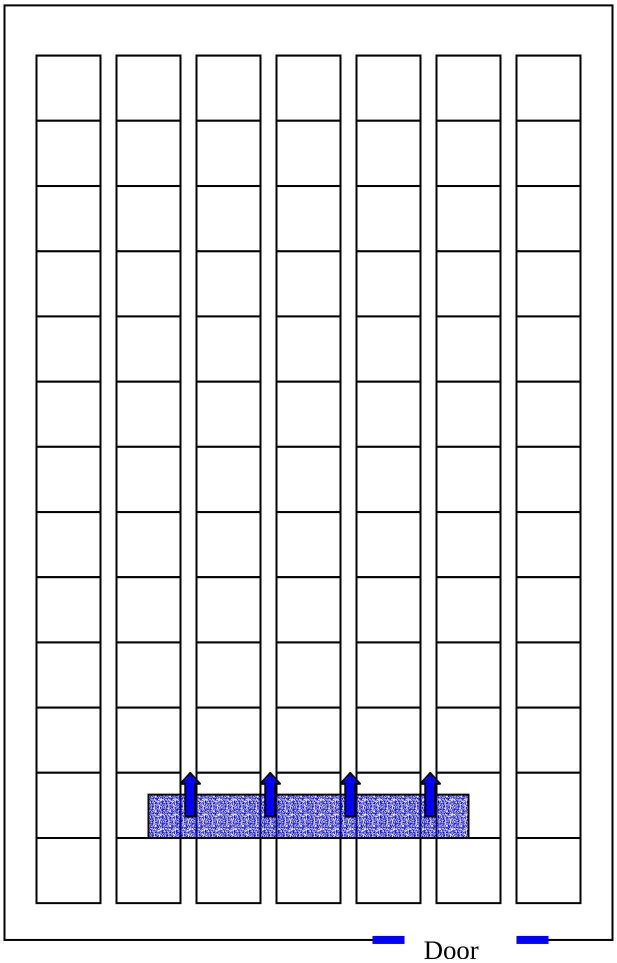

Figure 2. Tight Stacked Room.

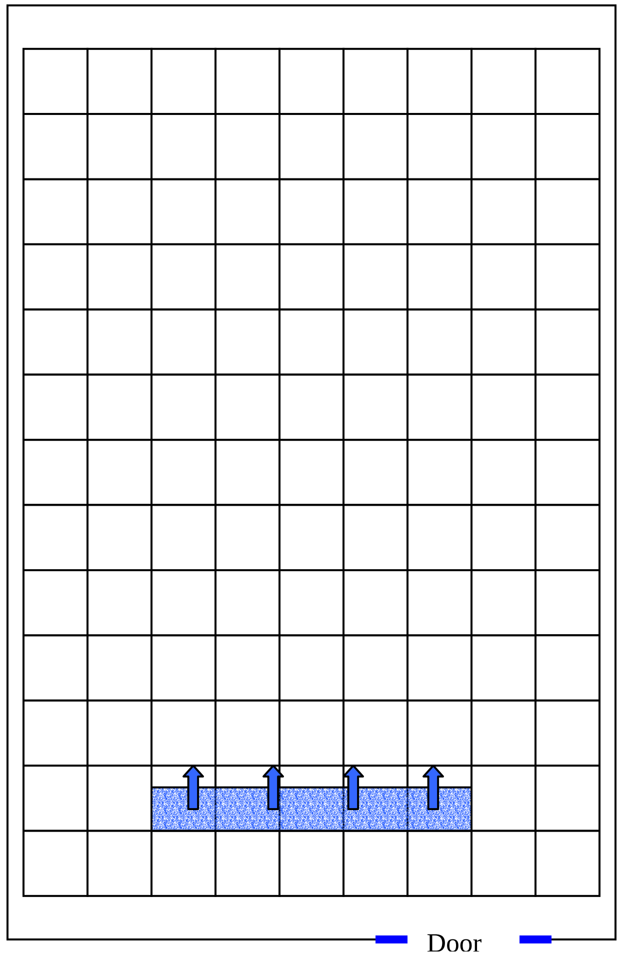

Figure 3. Bin stacking in one specific room.