

VISUAL DOCUMENTATION OF AIR FLOW PATTERNS IN A CONTROLLED ATMOSPHERE STORAGE

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Abstract

Rapid reduction of fruit temperature has long been recognized as a key parameter in extending post harvest fruit quality. Research documenting times required to cool apples and pears at various locations in two 1000 bin controlled atmosphere storage rooms provided evidence of non-uniform air circulation patterns (Hellickson, et al. 1996, 1997). Video documentation of neutrally buoyant helium filled soap bubble movement in one of the same rooms verified the non-uniform air circulation patterns. Bin spacing throughout the room and bin placement beneath the evaporator coil directly influenced air distribution uniformity and quantities that did not circulate through the cooling unit. Improved bin placement within storerooms may result in shorter cooling times, reduced energy consumption and improved fruit quality after extended storage periods.

1. Introduction

Regular and controlled atmosphere rooms used to store fresh apples and pears in bulk bins are typically equipped with large evaporator coils. Airflow rates created by their fans may range from 0.8 to 1.7 cubic meters per minute per bin (30 cfm to 60 cfm per bin). One or more temperature sensors in each room are used to control refrigerant flow through the evaporator units. The air temperatures being sensed are frequently averaged thereby providing a mixed air condition to the controller. Research that measured the times required to cool apples and pears at various locations in two 1000 bin controlled atmosphere storage rooms documented non-uniform fruit cooling at various locations. Continuous measurement of fruit temperatures in 27 bins located within two similar controlled atmosphere (CA) storage rooms documented that cooling efficiency was not uniform (Hellickson et al. 1996, 1997). Cooling efficiency was defined as defined at the time to cool fruit to 0 °C divided by initial fruit temperature minus 0 °C.

These differences in fruit cooling provided evidence of non-uniform air circulation patterns. Because refrigerant control was based on air temperature(s) measured above the fruit mass, areas with fruit at elevated temperatures could exist without being detected. Unless air circulation throughout the storage space is uniform, fruit in low flow areas will be warmer than fruit in higher flow areas. Respiration activity increases as fruit temperature increases. Increased respiration causes increased organic losses through

increased carbon dioxide production and transpiration of water vapor from the product. Therefore, this study was initiated with the following objective.

- Document air circulation patterns within a commercial fruit cold storage room where evaporator fans are operated full speed and bins are tight-stacked room.

2. Materials and Methods

Neutrally buoyant helium-filled soap bubbles were dispersed within a commercial sized fruit storage room filled with either wooden or plastic bins. One Krack model APPL 423 LLP FLA LH evaporator unit with a rated capacity of 808 kW (23 tons) of refrigeration was located above the door in the study room. The coil housed four 0.762 m (30 in) diameter fans each driven by a 1.5 kW (2 HP) motor. Total fan capacity was 24 cubic meters per second (50,700 cfm). Face velocity of air leaving the evaporator unit was calculated to be approximately 13.1 m/s (43 ft/s). Bubble movement was video taped and analyzed with either multiple frame capture software or slow motion to determine air movement at various locations within the 18.6 m long by 9.3 m wide by 8.8 m high (61 feet long by 30.5 feet wide by 29 feet high) room.

The evaporator unit was positioned 0.978 m (38.5 inches) in from the door wall. Space between the flat top of the unit and the ceiling was 0.165 m (6.25 inches) at the air inlet side and 0.140 m (5.5 inches) at the air outlet side (ceiling slope was approximately -1/48 from the door end to the rear of the room). Height of the evaporator unit was 1.105 m (43.5 inches) at the air inlet side and 0.972 m (38.25 inches) at the air outlet side. Space from the left side of the evaporator and the wall was 1.40 m (55.25 inches). Space between the evaporator unit and the right wall was 1.067 m (42 inches).

When wooden bins were stacked 10 high under the evaporator, space between the top of the bins and the bottom lowest part of the unit was 0.559 m (22 inches). When plastic bins were stacked 10 high under the evaporator, the space between the top of the bins and the lowest part of the unit was 0.152 m (6 inches). Space between the rear wall and bin stacks was approximately 0.559 m (22 inches). Space between the bin rows and side-walls of the room ranged from 0.178 m to 0.356 m (7 inches to 14 inches). The 0.356 m measurements were near the front (door end) of the room when six rows of bins were placed across the room.

Bin placement configurations investigated included:

- Empty wooden bins, tight-stacked in the room and placed 10 high, Fig 1.
- Empty wooden bins, tight-stacked in the room and placed 11 bins high, Fig 2.
- Filled plastic bins, tight-stacked in the room, placed 10 high with lime on top, Fig 3.
- Empty plastic bins, tight-stacked in the room, placed 10 high, Fig 4.

The following terminology is used to describe locations within the room where data were recorded:

- Rows of bins are identified as running from the door-end of the room to the rear of the room. There were 7 rows of bins in the tight-stacked areas. While standing in

the door facing into the room, Row 1 is nearest the left wall, and Row 7 is nearest the right wall.

- There were 14 Stacks of bins in the room. Stack 1 bins are nearest the door and Stack 14 bins are nearest the rear of the room.

3. Results

Empty wooden bins stacked 10 high. Air movement immediately in front of the evaporator unit was highly turbulent and frequently reversed direction. At one instant, bubbles moved rapidly away from the coil and the next, movement was rapidly toward the fans. This highly turbulent region existed from near the face of the evaporator unit (Stack 2) to approximately five full bins from the door wall (Stack 5). Bubble movement at Stack 6 became more linear toward the rear of the room. In general, bubbles in the area from Row 4 to Row 7 and Stack 6 to Stack 9 moved toward the rear of the room. Bubbles in the area from Rows 3 and 4 and Stack 6 to Stack 9 moved toward the left rear of the room. Bubble movement recorded near the back of the room tended to go over the last stack of bins and down. Bubbles near the right rear of the room migrated toward the rear wall, around the bins in Row 7-Stack 14, and continued back toward the front of the room in the space next to the right wall. Bubbles from the center of the last stack and to the left migrated over the edge of the bins and flowed toward the left rear corner. Some bubbles entered the runner space and some continued around the bins in Row 1-Stack 14. These bubbles continued in the space between the left wall and the bins eventually returning to the evaporator unit. Of significant interest was bubble movement in Rows 1 and 2 throughout the Stack 1-14 area. Although all four fans were operating at full speed, this space above the bins became an area of return-flow toward the evaporator unit. Figure 5 summarizes the airflow patterns observed for this stacking configuration.

Empty wooden bins stacked 11 high. Similar air movement in the area immediately in front of the evaporator was observed. Bubble movement in the space above Row 1 in the Stack 4-6 area was frequently toward the left wall and then back toward the evaporator. Flow in the Row 2-5 Stack 5-14 area was predominately toward the rear of the room. Although the stacking pattern near the door (Stacks 1-3) had only six rows across, the spaces was more uniformly distributed than in the 10 high configuration. Bubble movement at Stack 3 near both the left and right walls curved back toward the back of the evaporator. Bubbles released at Stack 14 Rows 2 and 3 generally moved toward the left rear of the room and went over the end bins. Some bubbles entered the bin runner spaces at various levels and some returned to the door end of the room in the space between the left wall and Row 1. Bubbles released at Stack 14 Rows 6 and 7 generally went directly over the end bins or flowed toward the right rear of the room and over the last stack of bins. Airflow patterns observed in the room for this stacking configuration are illustrated in Figure 6.

Filled plastic bins with lime on top stacked 10 high. Bins in Rows 1-7 and Stacks 4-14 each had a wooden pallet with two layers of lime placed on them. The space between the top of the lime and the ceiling was about 0.864 m (34 inches) at Stack 4 and 0.584 m (23 inches) at Stack 14. Bubble movement in the space above lime bags in the area from

Stack 6 to Stack 9 Rows 2-6 was mostly toward the rear of the room. Bubbles tended to move toward the left wall at Stack 6 Row 1 and toward the right wall at Stack 6 Row 7. Once the bubbles reached the wall, flow was back toward the evaporator. Bubbles released at Stack 11 Rows 2-4 flowed toward the left rear of the room. Bubbles at Stack 11 Row 1 moved toward the left wall and then flowed toward the evaporator. Bubbles released at Stack 12 Row 7 moved toward the right rear of the room.

Empty plastic bins stacked 10 high. Similar

Less air was able to pass underneath the evaporator with this configuration. The space between the top of the bins and the evaporator unit was reduced to approximately 0.1524 m (6 inches).

4. Discussion

Significant differences in air distribution was noted depending upon bin placement. Conventional stacking of bins within rooms attempts to maintain approximately 0.1524 m (6 inches) between rows that run perpendicular to the evaporator unit(s). When solid sided wooden are used to store fruit, this space does not enhance fruit cooling or temperature control. Air will attempt to flow through those spaces that present the path of least resistance. Primary cooling of fruit in wooden bins is achieved by passing air over the fruit in the runner space created when bins are stacked vertically. Unless air being circulated in the room is forced to enter the runner spaces,

5. Acknowledgements

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6. References

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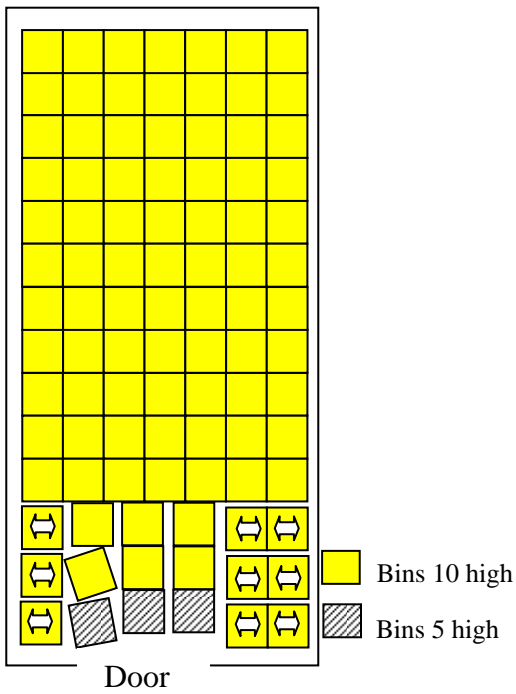


Figure 1. Empty Wooden Bin Stacking Pattern.

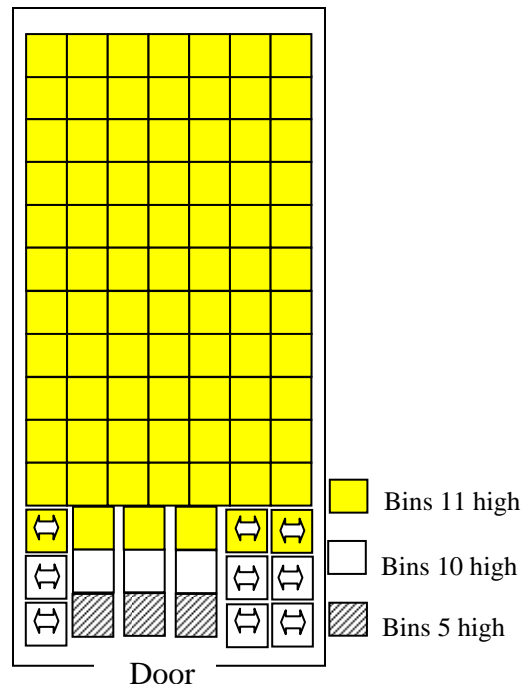


Figure 2. Empty Wooden Bin Stacking Pattern

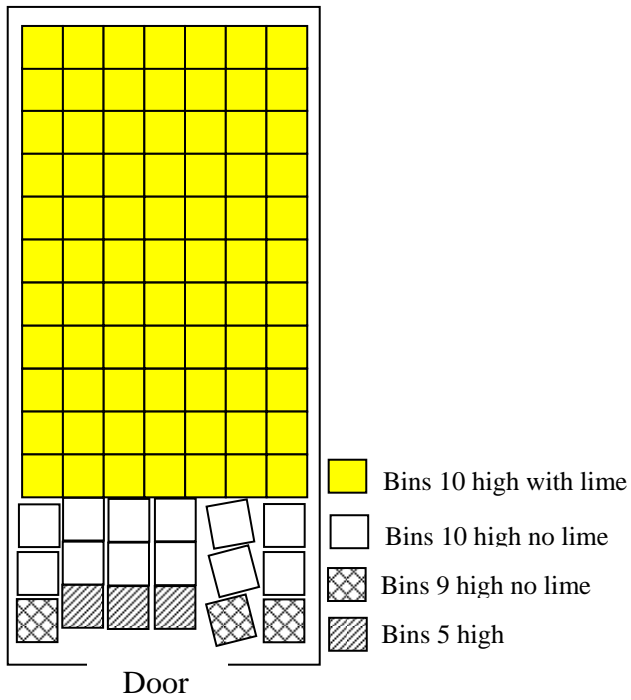


Figure 3. Filled Plastic Bin Stacking Pattern.

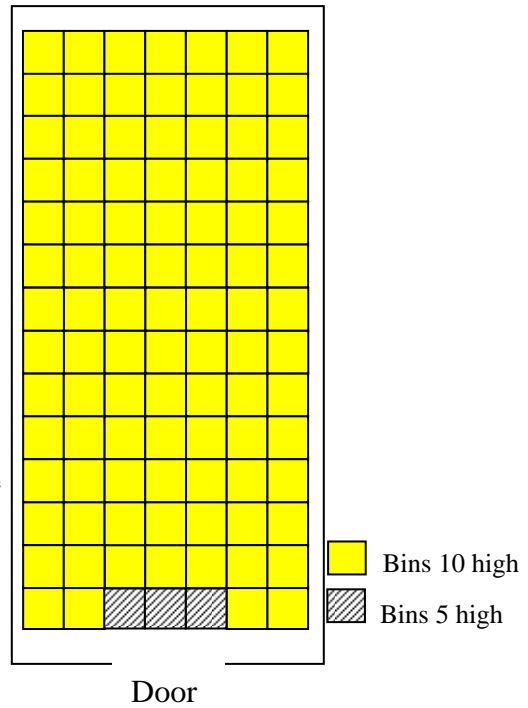


Figure 4. Empty Plastic Bin Stacking Pattern

Note: All bins with the symbol ⇔ are “cross-stacked”, which means the runner space of the bins in that stack are perpendicular to the runner spaces of all other bins in the room.

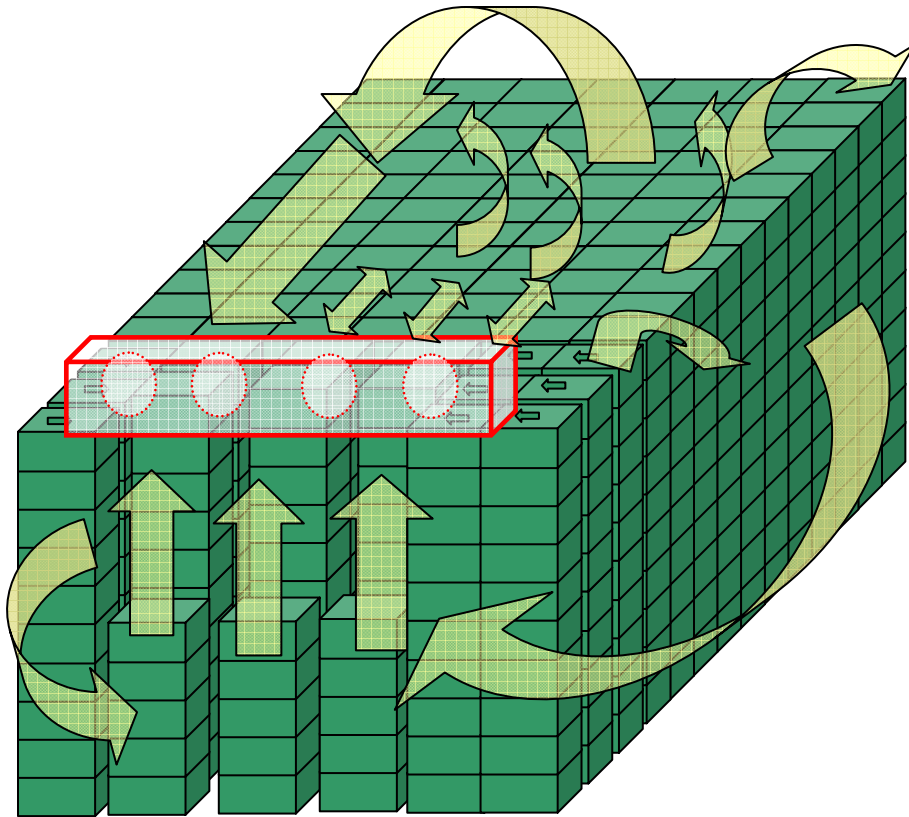


Figure 5. General airflow patterns in room with empty bins stacked 10 high.

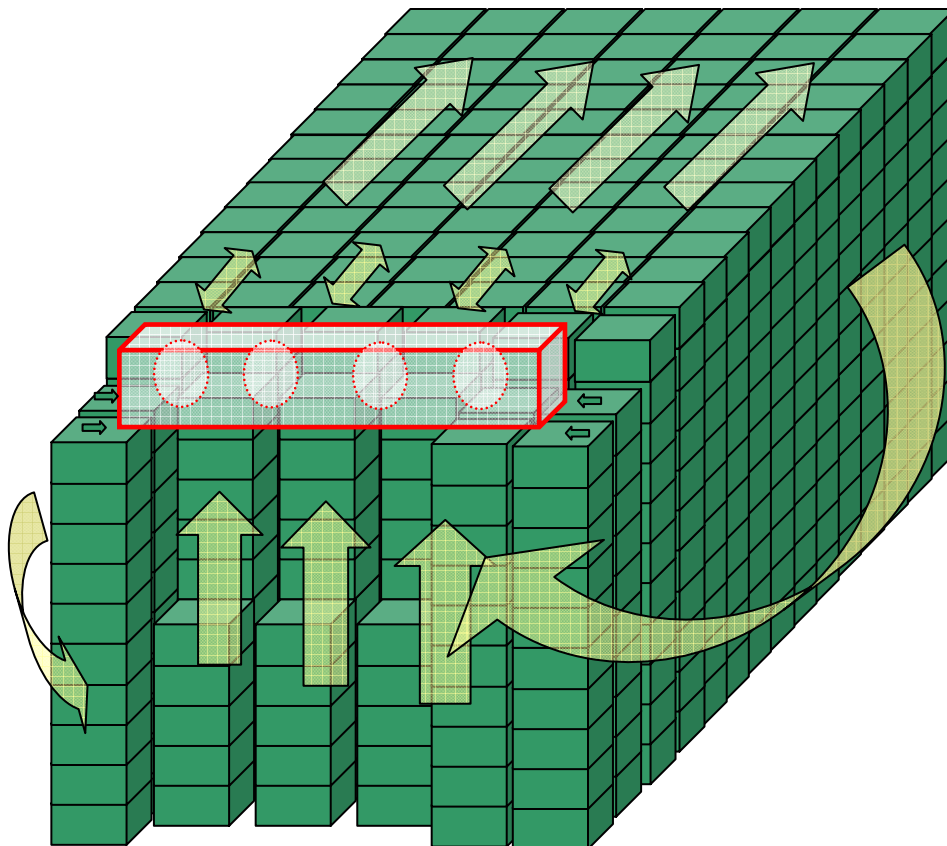


Figure 6. General airflow patterns in room with empty bins stacked 11 high.

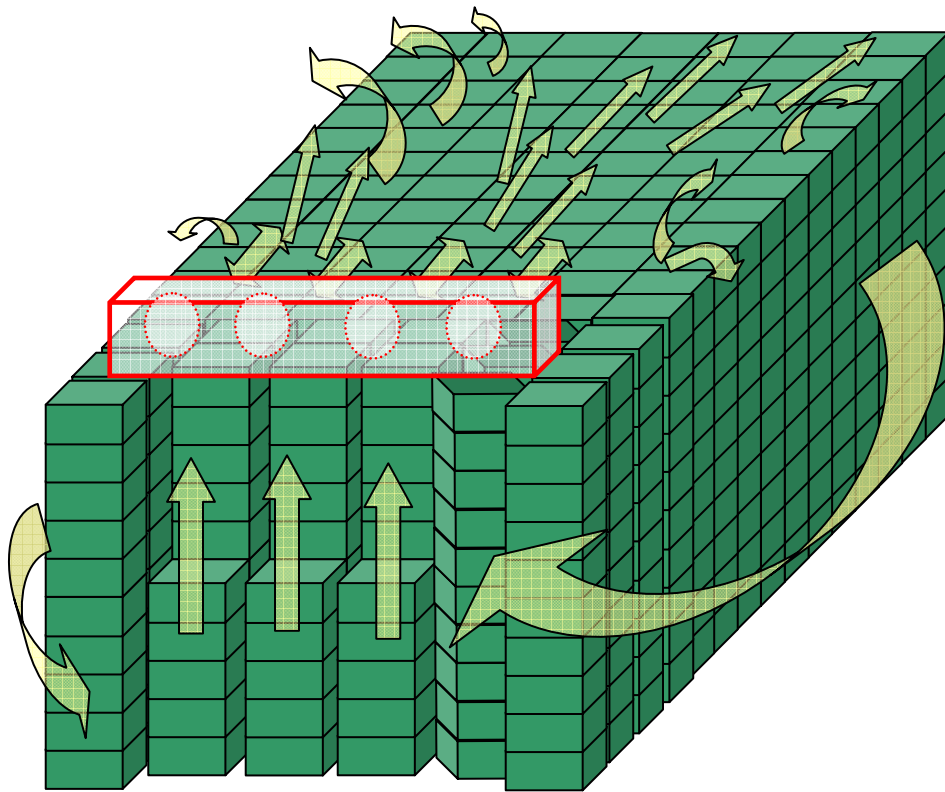


Figure 7. General airflow patterns in room with filled plastic bins, stacked 10 high with lime bags on top.

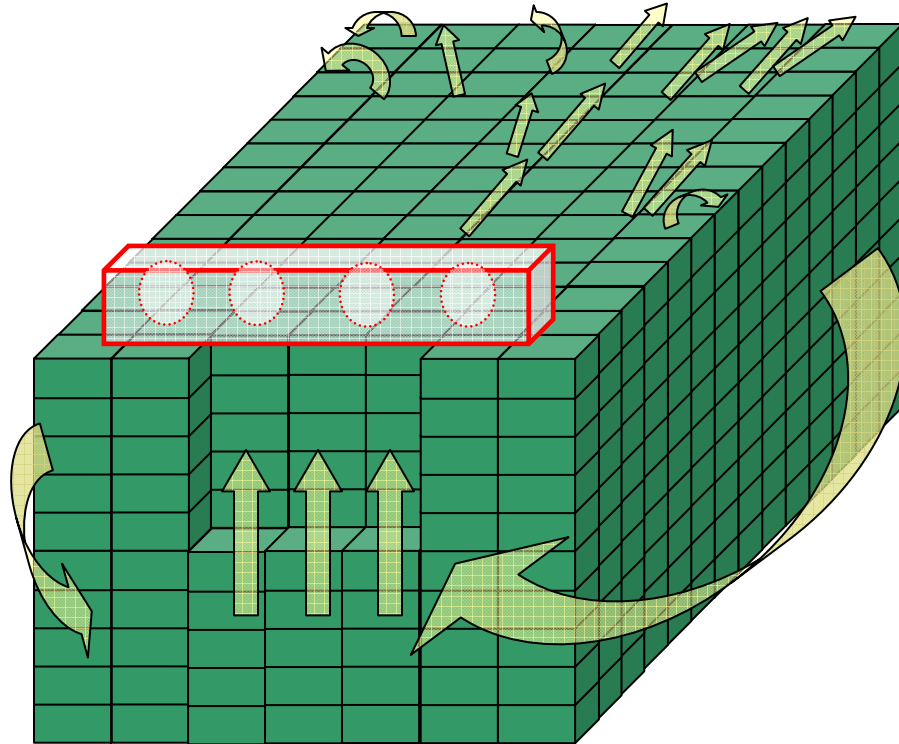


Figure 8. General airflow patterns in room with empty plastic bins stacked 10 high.